Centre for Doctoral Training

Connected Electronic and Photonic Systems

(CEPS)

MRes modules 2019-20

Course code: TMREENSIPE01

Contents

Module 1
Electronics components and systems
15 credits, choose 1

Radio Frequency Systems (RFS)

Location: University of Cambridge

Module code: UCAM-4B24

Lecturer: Dr Michael Crisp

Timing and Structure: Lent term. Assessment: 75% exam, 25% coursework.

Aims

The aim of the course is to provide a system level overview of RF and Microwave so that system performance can be predicted and optimised to meet a specification.

It is proposed that this module will focus on the system aspects of RF design (as opposed to circuits). Therefore, the overall aim is that circuits (amplifiers etc.) can be reduced to blocks with a minimum number of parameters from which the system performance can be estimated.

Objectives

By the end of the course students should be able to:

- Apply network analysis to an RF system.
- Understand the effects of noise, linearity and gain in cascaded RF systems.
- Be able to optimise impedance match of an amplifier as a trade-off of noise, linearity, bandwidth and stability.
- Understand the operation of passive RF networks (couplers, splitters, attenuators) and the limits on their performance.
- Identify a range of methods to improve amplifier performance.
- Understand a range of RF system applications and their performance requirements.

Content

1. **Network Analysis**
   - 2-port and multi-port devices
   - Impedance, scattering and transmission parameters, their relationships and uses
   - Signal flow graphs
   - Two port power gains

2. **Noise and distortion**
   - Noise sources in RF systems
   - Noise figure
   - Noise in passive networks
   - Noise of mismatched devices
   - Effects of Distortion

- Measures of distortion and intermodulation
- Dynamic range
- Noise and distortion of cascaded devices

3. **Impedance matching methods**
   - Limits on achievable matches
   - Distributed impedance matching methods
   - Broadband matching

4. **Amplifier design**
   - Stability
   - Conjugate matching
   - Design for low noise
   - Design for high power and low distortion

5. **RF system architecture**
   - Zero IF
   - Software defined radio

6. **RF system applications**
   - Radar
   - Passive RFID
   - Radio regulations

Coursework

CAD Amplifier design
Using industry standard software, the performance of a microwave low noise amplifier will be investigated to maximise performance. A brief ‘getting started’ demonstration will be given in lectures and a drop-in session organised for software trouble shooting.

Embedded Systems for the Internet of Things (EMBSYS)

Location: University of Cambridge

Module code: UCAM-4B25

Lecturer: Dr Phillip Stanley-Marbell

Timing and structure: Michaelmas term. Assessment: 100% coursework.

Prerequisites: 3B2 useful

Aims

The aim of the course is to introduce students to the principles and practice of computation and sensing systems that interact with the physical world.

Objectives

By the end of the course students should be able to:

- Define the role of uncertainty in measurements of physical signals and quantify measurement uncertainty for a given sensing system.
- Evaluate energy use in an embedded system using in-system current monitors.
- Define the role of noise in both measurements and displays and identify appropriate metrics to use in quantifying noise for a given design.
- Design communication subsystems and the required electrical circuit support between a collection of I2C- or SPI-interfaced sensor integrated circuits and an ARM Cortex-M0 microcontroller.
- Numerically quantify measurement uncertainty and noise in outputs given a system design.
- Recall and explain the interaction between displays and the human visual system.
- Design modifications to sensing, communication and display systems to improve their energy efficiency.
- Design the logical organisation and required firmware for new systems built around an ARM Cortex-M0 microcontroller and sensors or displays connected via I2C and SPI communication interfaces.

Content

The module will introduce students to the principles underlying sensor operation, signal acquisition, the role of measurement uncertainty and noise, common sensor communication interfaces and how they interact with modern embedded microcontrollers such as the ARM Cortex-M0 family. The module will link these concepts in the signal acquisition and processing chain to a study of output interfaces in embedded systems. This exploration of output systems will be built on a study of the principles of operation of OLED displays and how the flexibility of the human visual system enables interesting circuit- and algorithm-level techniques to reduce display power dissipation.

Lecture 1: System overview of sensing, computation, I/O, and displays in embedded systems; interpreting device and system datasheets. At the end of this lecture, students should be able to: enumerate the important components in an embedded system design; read and interpret the datasheet for a component in a system or for an entire system; propose and design changes to a system to extend its uses.

Lecture 2: Precision, accuracy, reliability, and measurement uncertainty. Noise sources in analogue and digital systems; role of signal gain and restoring logic. At the end of this lecture, students should be able to: define precision, accuracy, reliability and measurement uncertainty; analyse a system design and quantify these properties for a design's components; enumerate the sources of noise and measurement uncertainty in analogue and digital systems; propose design changes to improve the robustness of systems to noise.

Lecture 3: Embedded I/O interfaces: I2C, SPI, I2S, I3C, MIPI DSI, and MIPI CSI. At the end of this lecture students should be able to: enumerate the differences between the common embedded wired communication interfaces; select and substantiate a choice for an interface for a given design problem.

Lecture 4: C and assembly programming for embedded systems. At the end of this lecture, students should be able to: implement firmware that runs in the absence of an operating system and which contains a mixture of C and ARM assembly code.

Lecture 5: Embedded library and OS support overview; ARM Mbed OS API and TI-RTOS. At the end of this lecture students should be able to: design the firmware for an embedded sensing and computing problem using Mbed OS API calls for actions such as I/O.

Lecture 6: Case study.

Lecture 7: Field-programmable gate arrays in low-power embedded systems; Verilog overview. At the end of this lecture students should be able to: describe and explain the basic architecture of FPGAs; use their understanding of the Verilog hardware description language and FPGA synthesis tools to modify an existing Verilog design.

Lecture 8: Human colour vision perception and its interaction with OLED displays: their structure, interfaces and techniques for energy-efficiency. At the end of this lecture students should be able to: enumerate the properties of OLED displays; propose changes to existing system designs that use OLED displays in order to improve their energy efficiency; enumerate the basic properties of human colour vision that have a bearing on the design of displays for embedded systems.

Lecture 9: Physical invariants in embedded systems. At the end of this lecture students should be able to: define physical invariants in the context of a sensor-driven system; apply concepts from Lagrangians, Hamiltonians, the Euler-Lagrange Equations, Noether's theorem and recent research on inferring Lagrangians and Hamiltonians from sensor data to embedded systems designs.

Lecture 10: Wireless communications using Bluetooth, 802.15.4/Zigbee and LoRa; Bluetooth HCI interface. At the end of this lecture, students should be able to: enumerate the differences between the major low-power radio interfaces available for embedded or Internet-of-Things systems; propose energy-efficient choices for a wireless sensing system design given the application's design constraints.

Lecture 11: Schematic capture and basic printed circuit board layout using Eagle. At the end of this lecture students should be able to: create a design ready to be submitted for manufacturing (Gerber files) using the Eagle schematic capture and printed-circuit-board layout tools.

Lecture 12: Designing new embedded systems to solve a specified application need. At the end of this lecture students should be able to: propose an architectural design comprising sensing, computation, communication and display to address a given application need, with the design implementable, within the limitations of schematic capture and printed-circuit-board layout tools such as Eagle.

Coursework

Activity 1: OLED display control over SPI exercise
Obtain hands-on experience writing a device driver in C for an SPI peripheral, using the FRDMKL03 ARM board and the OLED display from the course hardware kit.

Activity 2: Project proposal one-page report
Identify an interesting engineering problem that can be addressed using an embedded system and the concepts, theory, techniques and tools covered in this course.

Activity 3: Power measurement using TI INA219 I2C device exercise
Obtain hands-on experience writing a device driver in C for an I2C peripheral, using the FRDMKL05 ARM board and the TI INA219 daughterboard from the course hardware kit.

Activity 4: Sensor interfacing from Lattice iCE40 FPGA exercise
Obtain hands-on experience implementing a design in the Verilog hardware description language.

Activity 5: Project interim report
Present progress made towards final project goals, evaluate lessons learned so far and obtain feedback and guidance on necessary plan adaptation.

Activity 6: Project concept, design, implementation and final report
Present the problem addressed, approach employed, system implemented and system evaluation.

Reading list

Introduction to Embedded Systems, A Cyber-Physical Systems Approach, ISBN: 978-0262533812.

An Introduction to Uncertainty in Measurement, ISBN: 978-0521605793.

Linkers and Loaders, ISBN: 978-1558604964.

The Circuit Designer's Companion, 3rd Edition, ISBN: 978-0080971384.

The Practice of Programming, ISBN: 978-0201615869.

Expert C Programming, ISBN: 978-0131774292.

C: A Reference Manual (5th Edition), ISBN: 978-0130895929.

Bluetooth Low Energy: The Developer's Handbook, ISBN: 978-0132888363.

Programming Embedded Systems: With C and GNU Development Tools, 2nd Edition, ISBN: 978-0596009830.

Embedded Systems Dictionary, ISBN: 978-1578201204.

The Art of Designing Embedded Systems, Second Edition, ISBN: 978-0750686440.

The Art of Electronics, ISBN: 978-0521809269.

Color Science: Concepts and Methods, Quantitative Data and Formulae, ISBN: 978-0471399186.

Electronic Sensors and Instrumentation (ELECSENS)

Location: University of Cambridge

Module code: UCAM-4B13

Lecturer: Dr Paul Robertson

Timing and structure: Lent term. 16 lectures (including examples classes). Assessment: 100% exam.

Aims

The aim of the course is to introduce students to state-of-the-art practice in electronic instrumentation systems, including the design of sensor/transducer elements for physical measureands, their respective interface electronics and precision measurement techniques.

Objectives

By the end of the course students should be able to:

- Design circuits to interface to simple temperature and strain measurement devices.
- Demonstrate a knowledge of frequency sources and measurement circuits.
- Measure high currents using 4 terminal devices and transformers.
- Describe how micro-machined silicon sensors are made, their operation and merits.
- Describe a range of ultrasonic transducers, their applications and associated electronics.
- Understand the operation of electromagnetic sensors for flux, current and position sensing.
- Design and analyse sensor circuits and estimate signal to noise ratios.
- Design an appropriate interface circuit for a sensor with given characteristics.
- Produce an outline design of an instrumentation system to monitor a range of physical parameters including pressure, temperature, flow, position and velocity.

Content

Temperature and strain sensors and interface electronics (3L)

- Description of thermocouples, thermistors and strain gauges and associated electronics.
- Drift, noise and bandwidth considerations, signal to noise ratio improvement.

Precision measurements (2L)

- Voltage measurements: thermal emfs, guarding, shielding. Precision ADC methods.
- Time and frequency measurements: stable frequency sources, timer-counter techniques.
- Current measurements: current transformers, 4-terminal measurements of high current.

Electromagnetic devices (4L)

- Selected revision of electromagnetic theory and its application to electronic sensors.
- Flux gate, inductive and Hall effect magnetic devices and interface electronics.
- Synchronous detection method applied to fluxgate sensor.
- Laser range finder and velocity sensing.

Microfabricated sensors (3L)

- Overview of silicon micromachining techniques and their application in accelerometers, gyroscopes, automotive air-bag sensors and pressure transducers.
- Physical principles of operation and related signal processing electronics.

Ultrasonic transducers (3L)

- Description of piezo-electric devices, theory and application in practical sensor designs.
- Case studies of the Polaroid range finder, Doppler motion detector and an electronic gas meter.
- Electronic circuits for driving transducers and signal detection methods.

Practical demonstration lecture (1L)

- Evaluation of micro-machined accelerometers and gyroscopes.
- Flux-gate magnetometer using synchronous detection.
- Ultrasonic motion and distance sensing.

RF Circuit and Systems (RFC)

Location: UCL

Module code: ELEC0115

Lecturer: Dr Chin-Pang Liu

Timing and structure: Term 2. Assessment: 75% exam, 25% coursework (2000 words).

Aims

This module aims to give students a good grounding in a range of RF devices including the fundamentals of device physics, RF circuits, system architectures and noise measurement techniques. The knowledge of impedance matching, stability and noise figure for amplifier circuit design learnt by the students will be consolidated with a full-day computer simulation exercise where students will perform RF amplifier design tasks using the industry standard software package Keysight ADS.

Objectives

At the end of the course, students should be able to:

- Understand the basic science and physical mechanisms underlying the operation of semiconductor RF devices.
- Understand the design, fabrication, packaging, operation and characteristics of a wide range of two and three terminal RF devices.
- Compare and contrast established and emerging RF device technologies for different applications, including understanding economic and manufacturing constraints.
- Analyse device performance and understand figures-of merit, limitations, design criteria and implications for circuits.
- Understand the design of RF circuits, key applications and integration technology.
- Understand the tools and analysis techniques used for RF circuit design and optimisation.

Content

- Review of carrier dynamics: effective mass, scattering, mobility; drift and diffusion currents; negative differential resistance.
- Two-terminal devices (Schottky and tunnel barriers, detector and mixer diodes, varactors, PIN switches, transferred electron devices and avalanche sources).
- Radio frequency CMOS technology.
- Comparison with other semiconductor technologies.
- Three-terminal devices (bipolar devices including SiGe and III-V HBTs, GaAs MESFETs, III-V HEMTs, and SiGe hetero structure MOSFETs).
- Microwave transmission line theory and scattering parameters.
- RF circuit design techniques in MIC and MMIC form.
- Amplifier gain, noise and stability analysis using scattering parameters.
- Applications: RF transmitters and receivers, amplifier linearisation, mixers, modulators.
- Integration technology and the design of monolithic RF circuits.
- Critical comparison of different RF technologies and manufacturing processes.

Module 2
Photonics components and systems
15 credits, choose 1

Photonic Systems (PHOTSYS)

Location: University of Cambridge

Module code: UCAM-4B11

Lecturer: Prof Tim Wilkinson

Timing and structure: Michaelmas term. 14 lectures. Assessment: 100% exam.

Prerequisites: 3B6 useful

Aims

The aims of the course are to:
- Understand how Fourier optics can be used to manipulate light in many applications.
- Examine the advance of optical techniques into electronic systems for computation and communications.
- Investigate the technology behind such potential applications.

Objectives

By the end of the course students should be able to:
- Explain a simple introduction to optical diffraction and Fourier optics.
- Apply Fourier techniques to simple optical spatial patterns.
- Understand the principles of optical correlation and holography.
- Understand the basic principles of liquid crystal phase modulation.
- Explain the principles and construction of spatial light modulators (SLMs).
- Understand the basic principles of free space optical systems and how to build them.
- Know the basic function of adaptive optical systems.
- Understand the properties of optical aberrations and how to correct them.

Content

This module examines:
- Two dimensional and three-dimensional transmission, storage and processing of information using free space optics are discussed.
- Applications such as computer-generated holography, optical correlation, optical switching and adaptive optics are highlighted through the use of liquid crystal technology.

Fourier Holograms and Correlation (5L)

- Basic diffraction theory, Huygens principle
- Fourier transforms and holography introduction and motivation
- Fourier transforms; theoretical and with lenses; resolution of optical systems
- Correlation and convolution of 2-dimensional signal patterns
- Dynamic and fixed phase holograms

Electro-Optic Systems (5L)

- Free space optical components; wave plates and Jones matrices
- Fundamentals of liquid crystal phase modulation
- Spatial light modulation and optical systems
- Holographic interconnects and fibre-to-fibre switching
- Wavelength filters and routing systems
- The BPOMF and 1/f JTC correlators

Adaptive optical Systems (4L)

- Adaptive systems in free space optics
- The power of phase conjugation
- Adaptive optical interconnects
- Optical aberrations and optical correction techniques

Demonstrations in the lectures will include:

- 2D Fourier transform and diffraction patterns
- Computer generated hologram for optical fan-out
- Optical beam steering with dynamic holograms on SLMs
- The JTC

Photonic Subsystems (PSS)

Location: UCL

Module code: ELEC0078

Module leader: Prof Cyril Renaud

Timing and structure: Term 2. Assessment: 100% exam.

Aims

The module aims to provide an in-depth understanding of the design, operation and performance of advanced photonic devices including light emitting diodes, LEDs, a range of semiconductor lasers, photodetectors, liquid crystal devices, photovoltaic solar cells for a variety of applications including optical communications and solar power generation.

Objectives

By the end of this module students will be expected to:

- Know and understand the scientific principles and methodology of light generation, detection and modulation and to use this to understand the operation and evolution of advanced photonic devices so that they can appreciate historical, current and future developments and technologies.
- Have a comprehensive understanding of the scientific principles of light generation, detection and modulation and to use this to understand the operation and evolution of advanced photonic devices and their use in telecommunications and in solar power generation.
- Know and understand the mathematical principles necessary to underpin their education in advanced photonic devices and apply mathematical methods, tools and notations proficiently in the analysis and solution of engineering problems.
- Be aware of developing technologies related to advanced photonic devices.

Content

This course covers materials and devices and examines how ingenious device design can overcome shortcomings in the materials, devices or their application. This module features several key advanced devices used in all areas of photonics such as high bit rate fibre, security imaging, waveguide and free space digital communications. The course takes place over four days, followed by a three-hour tutorial and an optional exam.

The following topics will be covered during the course:

- Crystals
- The electronic behaviour of semiconductor materials
- Principle of generation of light and its detection
- Quantum wells and quantum dots
- Semiconductor growth by molecular beam epitaxy (MBE)
- Light emitting diodes (LEDs)
- Coupling of LEDs and lasers to optical fibres
- Principle of operation of a laser
- The design of a variety of semiconductor lasers

Optical Fibre Communication (OFC)

Location: University of Cambridge

Module code: UCAM-4B23

Lecturer: Dr Seb Savory

Timing and structure: Lent term. Assessment: 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

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.
- Analyse performance metrics such as bit error rate for an optical fibre communication link.
- Understand the principles of coherent detection as opposed to direct detection receivers.
- Understand the role of digital signal processing and forward error correction in modern communication systems.
- Design an optical fibre communication link 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 base stations 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.

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 cut-off 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.

Coursework

For the coursework there will be two exercises each worth 12.5% in which students will be required to write Matlab programs to analyse more complex problems associated with the course.

Optical Transmission and Networks (OTN)

Location: UCL

Module code: ELEC0049

Module leader: Dr Robert Killey

Timing and structure: Term 2. Assessment: 100% exam.

Aims

This module aims to provide an advanced understanding of the physical layer of optical transmission systems and networks on different time- and length-scales. Optical networks include the description of optical networks as a set of optical links, including the principle of wavelength routing on different time-scales (static and dynamic).

On optical transmission the focus is on the elements of analysis and design of point-to-point optically amplified transmission systems as well as access applications. This provides in-depth understanding of optical transmission system design, optical amplifiers and amplified systems and the operation of wavelength division multiplexed systems.

Both linear and nonlinear sources of transmission impairments and their accumulation with distance and interaction with dispersion are analysed. The choice of modulation formats, fibre dispersion and electronic processing techniques are discussed with the aim of maximising the spectral efficiency, channel capacity and operating system margins.

Objectives

At the end of the course, students should be able to:

- Understand the principles of optically amplified optical transmission systems, power levels, noise accumulation and the trade-off between system capacity and reach.
- Carry out power budget calculations for optically amplified links.
- Understand signal transmission impairments: fibre dispersion, PMD, fibre nonlinearity, including Kerr nonlinearity and stimulated Raman scattering.
- Carry out calculations quantifying the effects of dispersion and nonlinearity on an optical link.
- Understand the concept of spectral efficiency; appreciate the difference between symbol rate and bitrate and describe the use of different modulation formats and other signal dimensions to increase capacity (such as polarization and phase).
- Clearly understand optical system performance metrics: signal-to-noise ratio, sources of noise, capacity and spectral efficiency.
- Understand trade-offs between optical systems capacity and reach, choice of modulation and detection formats, and implications on system performance.
- Understand and apply the principles of electronic processing (transmitter and receiver based) and the basics of coherent detection.
- Describe and analyse a variety of optical network architectures: access vs core, static vs dynamic operating on different time-and length-scales.
- Analyse and design network topologies and calculate their capacities.
- Have the knowledge and confidence to design optical communications links and networks on different time and distance scales.
- Describe current research trends and explain expected future directions.

Content

Single mode optical fibre propagation
The physical properties that effect the propagation of optical signals are explained and the techniques for modelling these are described:
- Attenuation
- Dispersion
- Polarisation mode dispersion
- Nonlinear effects
- Nonlinear Schroedinger Equation

Optically amplified systems and compensation
Optically amplified systems for long distance transmission and the techniques used to compensate for the fibre transmission impairments are described:
- Noise accumulation
- Dispersion compensation DCF
- Dispersion maps
- Electronic dispersion compensation

Advanced modulation formats
- Spectral efficiency
- IMDD and Phase Shift Keyed (PSK) formats
- OFDM
- Coherent systems
- Dual polarization QPSK
- Digital coherent transceivers
- Digital Signal Processing

Wavelength division multiplexing
The principle of WDM for increasing the system capacity, the properties components required and the additional propagation impairments that occur are described:
- AWG based Wavelength MUX/DEMUX
- EDFA: gain bandwidth and gain flattening
- Inter-channel nonlinear propagation impairments: FWM, XPM

Optical networks
Here examples of typical optical networks and their particular characteristics are described:
- Why route in the optical domain?
- Wavelength routed optical networks
- Dynamic optical networks (packet switching, optical burst switching, load balancing)

Reading list

Core and metro networks, Alexander Stavdas, Wiley Series in Communications, Networking and Distributes Systems, 2010 (covers both systems and networks).

Fiber-optic Communication Systems, Govind P Agrawal, Wiley-Interscience; 3rd edition, 2002.

Optical Fiber Telecommunications V B, Fifth Edition: Systems and Networks (Optics and Photonics), Kaminow, T Li and A E Willner, Academic Press; 5th edition, 2008.

Multiwavelength Optical Networks, T E Stern, G Ellinas and K Bala, Cambridge Univ Press, 2009.

Advanced Photonics Devices (APD)

Location: UCL

Module code: ELEC0109

Module leader: Dr David Selviah

Timing and structure: Term 2. Assessment: 100% exam.

Aims

This module aims to provide an in depth understanding at the device level of the optical sources, modulators, detectors and passive optical devices used in communications and other applications such as optical communications and solar power generation. This includes the design, operation and performance of advanced photonic devices such as light emitting diodes, LEDs, a range of semiconductor lasers, photodetectors, liquid crystal devices and photovoltaic solar cells.

Objectives

By the end of the course students should be able to:

- Understand fundamental physical principles of light generation, detection and modulation and to use this to understand the operation and evolution of advanced phototonic devices.
- Develop design skills including defining a problem and identifying the constraints, understanding user needs and cost drivers, understanding how creativity can be used to establish innovative solutions and designs for components to fulfil new needs ensuring that the device performance meets the required specifications.
- Understand the characteristics of particular device materials and device fabrication and to appreciate recent new developments.
- Understand the applications in which the advanced photonic devices are used, including fibre optic communications and solar energy generation.

Content

This module covers the fundamental semiconductor and light matter interaction theory, necessary to understand the operation of these devices, device fabrication and device characteristics. Example applications are given to highlight the typical performance characteristics of these devices.

Photonic materials and properties

Glass, crystals, rare earth-doping, semiconductors, bulk, Multiple Quantum Wells (MQW), Quantum dots, liquid crystal photon absorption, spontaneous emission, stimulated emission, non-radiative decay, birefringence, energy bands, temperature dependence, density of states, fermi level, quasi-fermi levels, direct and indirect bandgaps states in the gap, impurities and defects, carrier recombination, non-radiative recombination, radiative recombination, radiative efficiencies, lifetimes, electro-optic refractive index modulation: CIE, plasma effect, QCSE, non-linearities.

LEDs, lasers, amplifiers and optical filters

Gratings, fabrication techniques (fibre and semiconductors), photonic band gap structures. The rate equation model, spectral linewidth, LEDs, amplifiers, lasers, Fabry Perot cavity, ring cavity, laser noise, laser examples: VCSEL, DFB, DBR (including SG, SSG and DS-DBR), external, laser direct modulation, semiconductor laser fabrication (Waveguide, vertical cavity).

Photodetectors

PIN photodiode, solar cells, photo-multipliers, fabrication techniques (Mesa, capacitance, waveguide or vertical structure).

Elective modules
15 credits each, choose 2

Quantum and Nano-technologies (NANO)

Location: University of Cambridge

Module code: UCAM-4B5

Module leader: Dr Colm Durkan

Timing and structure: Michaelmas term. 14 lectures + examples class. Assessment: 100% exam.

Prerequisites: 3B5

Aims

The aims of the course are to:

- Understand the basic principles behind quantum mechanics and be able to apply it to problems relevant to Electrical Engineering.
- Explore the concepts of quantum information processing and quantum computing.
- Become familiar with nanotechnology, what it is, where it is used, and how it relates to quantum systems.

Objectives

By the end of the course students should be able to:

- Apply quantum principles to understand charge transport and current flow at the nanoscale.
- Understand quantum confinement, the origin of band structure, and how it relates to quantum size effects.
- Be able to predict basic electrical properties of materials.
- Understand and explain the principles behind thermal conductivity of materials.
- Describe the operation principle of a quantum computer.
- Explain the principles behind quantum encryption.
- Understand the basic relationships between size and properties of materials, their quantum origin, and their application via nanotechnology.
- Know how to measure and explore properties of nanostructures.

Content

This module will introduce (building on material in 3B5) the concepts underlying quantum mechanics and nanotechnology and how to apply them to problems relevant to electrical engineering. We will explore the quantum origin of many of the properties of materials, ranging from resistivity, mechanical properties, colour, and band structure, and how these properties evolve with size. We will approach this from two angles: from the theoretical principles and predictions of quantum mechanics, to the manifestations of these as exploited using nanotechnology.

Lecture content

- The need for quantum description of the world around us.
- The basic assumptions of quantum mechanics.
- Solutions to the Schrodinger equation - confinement, band structures, quantum harmonic oscillator.
- Interpretation of quantum mechanics.
- Everyday examples of quantum mechanics at work.
- A quantum description of electrical properties of materials, and where Ohm's law comes from.
- Mesoscopic transport and the Landauer-Buttiker formalism.
- A look into the principles underlying quantum information processing.
- Entanglement, encryption and quantum computing.
- Nanotechnology: what it is and relationship to quantum mechanics.
- Nanomaterials, evolution of properties of materials with decreasing size, dimensionality.
- Ultimate nanostructures - graphene, molecular systems, novel device architectures.
- Exploring nanostructures - seeing atoms, scanning probe microscopy - see an AFM in operation.

Demonstrations during the lectures will include:

- Seeing an Atomic Force Microscope (AFM) up close and exploring how it works.
- Seeing some everyday nanostructured materials in nature.

Analogue Integrated Circuits (AIC)

Location: University of Cambridge

Module code: UCAM-4B21

Lecturer and Lab Leader: Dr Sanjiv Sambandan

Timing and structure: Michaelmas term. 16 lectures (including examples classes and case studies). Assessment: 100% exam.

Prerequisites: 3B1, 3B2, 3B5 assumed; 3B3, 3B6 useful.

Aims

The aim of the course is to provide a firm foundation and problem-solving skills for students to design and analyse complementary metal oxide semiconductor (CMOS) analogue circuits.

Objectives

By the end of the course students should be able to understand:

- The MOSFET: device, DC behaviour and AC/small signal behaviour.
- Techniques for DC and small signal analysis of MOSFET circuits.
- MOSFET voltage amplifiers and their small signal behaviour.
- The impact of high frequency operation on MOSFET circuits.
- Key parameters for the design of good biasing circuits.
- Noise in circuits, the techniques to analyse noise in circuits.
- The implication of feedback and its impact on stability, noise and performance.
- The impact of nonlinearity in circuits and the design of circuits that operate in the nonlinear domain.
- The fundamentals of the BJT, its small signal analysis and view the similarities and differences in MOS and BJT circuits.

Content

This course will cover the major aspects of the design and fabrication of analogue integrated circuits. It will provide students with the problem-solving skills to design and analyse complementary metal oxide semiconductor (CMOS) analogue circuits. It is intended to make graduates become more competitive to a large industrial segment looking for circuit designers, especially those skilled in analogue and mixed signal circuit design. Topics addressed will include:

1. Introduction to MOSFETs (1L)

- MOSFET current voltage characteristics: linear and saturation operation, channel length modulation
- Small signal analysis techniques: transconductance, output impedance due to channel length modulation, small signal resistance, methods to identify impedance at a node, methods to calculate gain, small signal circuit of MOSFETs
- PMOS, NMOS, CMOS
- Scaling

2. MOSFET as a switch (1L)
- Operation as a switch
- Switch-capacitor circuits: dynamics, time constants, parasitics clock feedthrough, charge injection
- Charge sharing between capacitors

3. Single stage MOS voltage amplifiers (4L)
- Voltage amplifiers: single stage topologies: common source, common source with degeneration, common gate, common drain, cascode
- CMOS technology and CMOS amplifiers
- Small signal, low frequency analysis of MOS single stage voltage amplifiers
- Small signal, high frequency analysis of MOS single stage voltage amplifiers, Miller effect, transit frequency, dominant pole

4. MOS differential amplifiers (2L)
- Concept and operation of differential amplifiers
- Analysis of MOS differential amplifiers: differential gain, common mode gain, CMRR
- Differential amplifiers with Active CMOS loads: differential gain, common mode gain, CMRR
- Half circuit method

5. Biasing circuits (1L)
- 2 MOSFET current mirror
- Impact of channel length modulation
- Cascode current mirror
- Temperature independent biasing

6. Noise (1L)
- Noise in circuits: characterisation of noise, noise spectrum
- Types of noise: thermal noise, flicker noise, shot noise and their noise spectrum
- Noise in RC circuits
- Noise in MOSFETs: corner frequency, analysis of noise in MOS voltage amplifiers, calculations of output and input referred noise in MOS circuits, signal to noise ratio

7. Feedback (2L)
- Concept of feedback
- Impact of feedback on the performance of circuits

8. Operational amplifiers (1L)
- OPAMP architectures
- Gain boosting
- PSRR, CMRR, slew rate

9. Nonlinear analog circuits (1L)
- Oscillators
- Phase locked loops

10. BJTs and BJT circuits (1L)
- BJTs current voltage characteristics: device operation, active mode, saturation mode, cut-off mode, base width modulation
- Small signal analysis of BJTs
- BJT based single stage voltage amplifiers: common emitter, common collector, common base amplifiers

11. Discussion of Example Problems (1L)

Computer Vision (COMPVIS)

Location: University of Cambridge

Module code: UCAM-4F12

Lecturers: Prof Roberto Cipolla, Dr Richard Turner

Timing and structure: Michaelmas term. 16 lectures (including 3 examples classes).
Assessment: 100% exam.

Aims

The aims of the course are to:

- Introduce the principles, models and applications of computer vision.
- Cover image structure, projection, stereo vision, structure from motion and object detection and recognition.
- Give case studies of industrial (robotic) applications of computer vision, including visual navigation for autonomous robots, robot hand-eye coordination and novel man-machine interfaces.

Objectives

By the end of the course students should be able to:

- Design feature detectors to detect, localise and track image features.
- Model perspective image formation and calibrate single and multiple camera systems.
- Recover 3D position and shape information from arbitrary viewpoints;
- Appreciate the problems in finding corresponding features in different viewpoints.
- Analyse visual motion to recover scene structure and viewer motion, and understand how this information can be used in navigation.
- Understand how simple object recognition systems can be designed so that they are independent of lighting and camera viewpoint.
- Appreciate the industrial potential of computer vision but understand the limitations of current methods.

Content

Introduction (1L)
Computer vision: what is it, why study it and how? The eye and the camera, vision as an information processing task. A geometrical framework for vision. 3D interpretation of 2D images. Applications.

Image structure (3L)
Image intensities and structure: edges, corners and blobs. Edge detection, the aperture problem. Corner and blob detection. Contour extraction using B-spline snakes. Texture. Feature descriptors and matching.

Projection (3L)
Orthographic projection. Planar perspective projection. Vanishing points and lines. Projection matrix, homogeneous coordinates. Camera calibration, recovery of world position. Weak perspective and the affine camera. Projective invariants.

Stereo vision and Structure from Motion (3L)
Epipolar geometry and the essential matrix. Recovery of depth. Uncalibrated cameras and the fundamental matrix. The correspondence problem. Structure from motion. 3D shape from multiple view stereo.

Object detection and recognition (3L)
Basic target detection and tracking. Machine learning for object detection and recognition. Random decision forests, support vector machines and boosting. Deep learning with convolutional neural networks.

Example classes (3L)
Discussion of examples papers and past examination papers.

Advanced Information Theory and Coding

Location: University of Cambridge

Module code: UCAM-4F5

Lecturers: Dr Jossy Sayir, Prof Ioannis Kontoyiannis

Timing and structure: Lent term. 16 lectures. Assessment: 100% exam.

Prerequisites: 3F7 assumed, 3F1, 3F4 useful but not necessary. The main pre-requisite is a good background in probability and information theory. 3F1, 3F4 and 3F7 useful.

Aims

The aims of the course are to:

- Learn about applications of information theory to universal data compression, statistics and inference.
- Introduce students to the principles of algebraic coding and Reed Solomon coding in particular.
- Give students an overview of cryptology with example of techniques that share the same mathematical background as algebraic coding.

Objectives

By the end of the course students should be able to:

- Appreciate the connection between information-theoretic concepts and fundamental problems in statistics.
- Demonstrate knowledge of core information-theoretical tools that can be used in probability and statistics.
- Show good understanding of the foundations of the problem of universal data compression.
- Use the basic results in large deviations theory, especially as applied in information theory and communications.
- Demonstrate a practical understanding of the algebraic fundamentals that underlie channel coding and cryptology.
- Understand the properties of linear block codes over finite fields.
- Implement encoders and decoders for Reed Solomon codes.
- Understand methods and aims in cryptology (including cryptography, crypt- analysis, secrecy, authenticity).
- Provide one example each of a block cipher and a stream cipher.
- Implement public key cryptosystems, in particular the Diffie-Hellman and Rivest- Shamir-Adleman (RSA) systems.

Content

This course will introduce students to applications of information theory and coding theory in statistics, information storage, and cryptography.

The first part of the course will discuss applications of information theory to universal data compression, statistics and inference.

The second part of the course will expand linear coding principles acquired in 3F7 to non-binary codes over finite fields. After establishing the algebraic fundamentals, we will cover Reed-Solomon coding, a technique used in a wide range of communication and storage systems (hard disks, blu-ray discs, QR codes, USB mass storage device class, DNA storage, and others).

The final part of the course will introduce the discipline of cryptology, which includes cryptography, the essential art of ensuring secrecy and authenticity, and cryptanalysis, the dark art of breaking that secrecy. The course will cover a number of methods to provide secrecy, ranging from mathematically provable secrecy to public key methods through which computationally secure communication links can be established over public channels.

Information theory and statistics (7-9L)

- Source coding, probability of error, error exponents
- Method of types, error rates in data compression and hypothesis testing
- Fundamental limits of estimation and hypothesis testing: The Cramer-Rao bound, Chernoff information, Neyman-Pearson tests, Stein's lemma, strong converses
- Large deviations: Cramer's theorem, Sanov's theorem, the conditional limit theorem
- Entropy and Poisson approximation
- Universal source coding: the capacity-redundancy theorem, the price of universality, Rissanen's lower bound

Introduction to practical number theory and algebra (2-3L)

- Elementary number theory
- Groups and fields, extension fields
- 3 equivalent approaches to multiplication in extension fields
- Matrix operations and the Discrete Fourier Transform

Algebraic Coding (3L)

- Linear coding and the Singleton Bound
- Distance profiles and MacWilliams identities
- Blahut's theorem
- Reed Solomon (RS) codes
- Encoding and decoding of RS codes

Introduction to Cryptology (2-3L)

- Overview of cryptology
- Stream ciphers, examples
- Block ciphers, examples
- Public key cryptography, basic techniques

Reading list

Elements of Information Theory, T. M. Cover & J. A. Thomas, Wiley-Interscience, 2nd Ed, 2006.

Information Theory: Coding Theorems for Discrete Memoryless Systems, I. Csiszàr & J. Körner, Cambridge University Press, 2nd Ed. 2011.

The Theory of Error-Correcting Codes, F. J. MacWilliams & N. J. A. Sloane, North Holland.
Algebraic Codes for Data Transmission, Richard E. Blahut, Cambridge University Press, 2003. (Online 2012)

Flexible and Stretchable Electronics (FLEXE)

Location: University of Cambridge

Module code: UCAM-GRM3

Lecturers: Dr Felice Torrisi, Dr Tawfique Hasan, Dr Luigi Occhipinti

Timing and structure: Lent term. 16 lectures including example classes. Assessment: 100% exam.

Prerequisites: Recommended (not mandatory): 4B5 Nanotechnology; 3B5 Semiconductor Engineering.

Aims

Next generation electronic applications will require a higher degree of mechanical flexibility to meet the demand for wearable and conformable electronic devices. The aim of the course is to cover the materials, processes, technology and applications behind the flexible electronics context and highlight the technological developments that have occurred in this rapidly evolving field.

Objectives

By the end of the course the student should be able to:

- Describe the various materials and production techniques for flexible thin films in electronics.
- Explain the sheet to sheet and roll to roll processing, coating and encapsulation techniques.
- Apply the theory of Film-on-Foil to calculate the strain in the foil substrate and in the thin film.
- Describe the production processes and the electronic transport in amorphous and polycrystalline silicon films, polymers and nanomaterials: explain advantages/disadvantages.
- Describe the effects of strain on the electrical characteristics (I-V curve, mobility, conductivity) and parasitic elements (overlap capacitances, contact resistance) of a Thin Film Transistor.
- Describe effects of torsion, tension, compression on stretchable devices.
- Explain the basics of effects of downscaling in flexible TFTs and compare TFT vs MOSFET.
- Design a flexible and transparent conducting film in terms of electrical sheet resistance and optical transparency. Describe ITO as flexible transparent conductor and suitable alternative materials.
- Discuss the integration techniques: Chip-on-flex, flex on flex, foil on foil, printed wiring of ultrathin chip. Integration techniques for stretchable devices.
- Discuss and compare advantages and disadvantages of organic vs inorganic flexible thin film transistors. Discuss frequency limitations of OTFTs (testing: ring oscillator).
- Explain the rheological and morphological requirements to design printable inks. Discuss advantages and disadvantages of printed electronic components.
- Explain the basics of the electrical percolation theory in networks of nanomaterials.
- Describe applications of flexible electronic devices in electronics, optoelectronics and energy.

Content

Due to the vast number of different flexible electronic components that are in production today, the course will be centred on three of the biggest growth areas: the materials and properties of thin films, the flexible electronic components and the heterogeneous integration and the large area flexible electronics.

The module will introduce basic concepts, a theoretical background (e.g. theory of film-on-substrate foil, two and three-layer point bending, theory of electronic bands in organic semiconductors) and the materials, before gradually moving into device design, presenting case studies of Thin Film Transistor (TFT) fabrication and characterisation (with emphasis on TFT vs MOSFET and effects of downscaling).

Case studies of practical applications such as flexible OLED, flexible photovoltaic device and flexible displays will be presented.

Introduction (2L)
- Overview of flexible and stretchable electronics technology and beyond.
- Thin-film electronic devices on flexible substrate. Example: from MOSFET to Thin Film Transistor (TFT).

Materials production, processing and properties (3L)
- Revision of electronic structure of solids and introduction of electronic structure in polymers.
- Metals, amorphous/polycrystalline silicon materials for flexible TFTs, flexible conducting and semiconducting oxides.
- Polymers and nanomaterials for flexible and stretchable conducting and semiconducting thin films

Mechanics of flexible and stretchable thin-films (2L)
- Mechanics of a thin-film on flexible substrate. Case study: ITO on flexible substrates, failure mechanisms.
- Emerging 1D, 2D nanomaterials and polymers for highly flexible and stretchable thin-films.

Flexible components and heterogeneous integration (4L)
- Flexible device case studies: TFTs, photodetectors and photovoltaic devices.
- Heterogeneous integration: Chip-on-flex, flex-on-flex, foil-on-foil, printed wiring of ultrathin chip. Chemical, mechanical and environmental stability of devices.
- Processes for large-area flexible electronics: roll-to-roll vs batch-to-batch, printing vs transferring.
- Hybrid integration techniques for stretchable electronics: Stretchable thin film devices and circuits.

Applications (3L)
- Flexible displays, touch sensors and systems
- Wearable electronic devices
- Printed flexible electronic sensors

Example class (2L)
- Study of the strain in the substrate and in the flexible film as function of the induced stress.
- Design and modelling of thin-film transistors.
- Design of flexible transparent and conducting films for display applications.

Devices for high frequency Electronics and Biosensing

Location: University of Cambridge

Module code: UCAM-4B26

Lecturers: A Lombardo

Timing and structure: Lent term. 15 lectures and 1 example class. Assessment: 100% exam.

Prerequisites: Recommended 3B5, 3B1; useful 4B24.

Aims

This course aims to introduce advanced active devices for integrated electronics, with particular emphasis on microwave, mm-wave, THz and biosensing.

Objectives

By the end of the course the student should be able to understand:

- The importance of active devices in high frequency circuits and systems.
- Learn fundamental physics and operation of advanced high frequency devices such as RF MOSFET, HEMT and HBT.
- The role of material in active high frequency devices, advantages and limitation of current technologies and potential offered by new materials.
- 2D/layered materials and the novel device concepts they enable.
- The basics of mm-wave and THz physics, their application and the technology requirement for such high frequency.
- Interaction between micro and mm-wave and biological materials and their use in biosensing (impedance spectroscopy), in particular at molecular and cell level.
- Leant state-of-the-art devices (waveguides, resonators, microfluidics, etc.) used for micro and mm-wave biosensing.
- Fabrication methods for high frequency integrated circuits (in particular MMIC) and advantages and challenges related to introduction of new materials. Also, appreciate the importance of integrating new materials and existing technologies.

Content

The course will provide a comprehensive review of state-of-the-art active devices used in high frequency applications (such as MOSFET, HEMT and HBT) as well as introducing novel devices enabled by new materials such as graphene and transition metal dichalcogenides (TMD). A significant part of the course will be dedicated to mm-wave and THz electronics, introducing fundamental physics, enabling technologies and applications. The focus then will shift towards biological applications of high frequency devices, in particular for sensing using micro and mm-wave at molecular and cell level. Finally, fabrication techniques for devices and integrated circuits will be discussed, with particular attention on the integration of novel materials with established technologies.

Introduction to high frequency electronics (1h)

- RF, microwave, mm-wave and THz
- Brief history of high frequency electronics
- Advantages and challenged of increasing frequency
- Enabling technologies: planar (monolithic and hybrid) and waveguide circuits
- The role of active devices in high frequency circuits and systems

Semiconductor micro and mm-wave transistors (4h)

- High frequency field effect transistors (FETs)
- High electron mobility transistors (HEMTs)
- Heterojunction bipolar transistors (HBT)
- High frequency passive components

Novel devices based on 2D/layered materials (4h)

- 2D/layered materials and heterostructures
- Graphene FETs
- Gate-modulated Schottky barrier transistors
- Tunnel transistors based on graphene
- Band to band tunnelling devices based on transition metal dichalcogenide
- Hot electron transistors

mm-wave and THz electronics (3h)

- Introduction to mm-wave and THz
- Applications
- Time domain and CW
- Sources: electronic (GUNN diodes, etc.) and QCL
- Detectors: thermal (bolometers, etc.) and integrated (Schottky, FET)
- Applications: communication, spectroscopy, imaging
- THz applications based on 2D/layered materials

Microwave and mm-wave biosensing (2h)

- Interaction between microwaves and biological materials
- Impedance spectroscopy
- Sensors types: waveguide, resonators, etc.
- Miniaturized devices and systems

Technology and integration (1h)

- Planar technology and MMIC fabrication
- New materials: advantages and challenges
- Heterostructures assembly
- Integration: hybrid, monolithic, etc.

Example class (1h)

Reading list

Ghione and Pirola, “*Microwave Electronics*”, Cambridge University Press, 2017.

Pozar, *“Microwave Engineering”*, Wiley, 2011.

Li et al., *“Principle and applications of RF/Microwave in Healthcare and Biosensing”*, Elsevier, 2017.

Image Processing and Image Coding (IMPROC)

Location: University of Cambridge

Module code: UCAM-4F8

Lecturers: Prof Nick Kingsbury and Dr Joan Lasenby

Timing and structure: Lent term. 16 lectures (including examples classes). Assessment: 100% exam.

Prerequisites: 3F1 assumed; 3F3, 4F7 useful.

Aims

The aim of the course is to introduce the key tools for performing sophisticated processing of images by digital hardware.

Objectives

By the end of the course students should be able to:

- Understand the main elements of 2-dimensional linear system theory.
- Design linear spatial filters for a variety of applications (smoothing etc).
- Understand techniques for the restoration and enhancement of degraded images.
- Show familiarity with the main characteristics of the human visual system with particular reference to subjective criteria for image data compression.
- Understand techniques for image coding using transform methods including the Discrete Cosine Transform (as used in the JPEG coding standard) and overlapped transforms.
- Understand methods for coding transform coefficients to provide maximum data compression.

Content

Sophisticated processing of images by digital hardware is now fairly common and ranges from special effects in video games to satellite image enhancement. Three of the main application areas are video data compression, image enhancement and scene understanding.

This module introduces the key tools for performing these tasks, and shows how these tools can be applied. The module will be split into two courses of 8 lectures each: image processing and image coding. Lectures are supported by computer demonstrations. There will be one examples sheet for each of the two 8-lecture sections.

Image Processing (8L)

This course covers the topics relevant to most aspects of image processing:

1. Two-dimensional linear system theory, as applied to discretely sampled systems:

- The continuous 2D Fourier transform and its properties
- Digitisation, sampling, aliasing and quantisation
- The discrete 2D Fourier transform (DFT)

2. 2D Digital Filters and Filter Design
- Zero phase filters
- Ideal 2D filters: rectangular and bandpass
- Filter design: the window method

3. Image Deconvolution
- Deconvolution of noiseless images - the inverse filter
- The Wiener filter (conventional and Bayesian derivations)
- Maximum Entropy deconvolution

4. Image Enhancement
- Contrast enhancement
- Histogram equalisation
- Median filtering

Image Coding (8L)

This course concentrates on image and video data compression techniques:

1. Characteristics of the human visual system which are important for data compression
- Spatial and temporal frequency sensitivities
- Distortion masking phenomena
- Luminance and colour (chrominance) processing

2. 2D block transforms and wavelet transforms
- Discrete cosine transforms
- Bi-orthogonal and orthonormal wavelet transforms
- Energy compaction properties of transforms for typical images

3. Optimal quantisation techniques of coding transform coefficients for maximum data compression
- Huffman coding
- Run-length coding
- JPEG 2-dimensional run-size coding

4. Video coding techniques
- Motion analysis
- Motion vector coding
- MPEG coding standards

Physics and Optics of Nano-structures (PON)

Location: UCL

Module code: ELEC0057

Module leader: Dr Oleg Mitrofanov

Timing and structure: Terms 1 and 2. Assessment: 100% exam.

Aims

The aim of the course is to provide an introduction the diverse field of nano-optics.

Objectives

By the end of the course students should be able to understand:

- The Physics and Optics of sub-wavelength and low-dimensional structures.
- Beyond the diffraction limit including applications in near-field microscopy.
- How to enhance light-matter interactions through use of micro-cavities and resonators.
- How to develop nano-structured devices such as photonic crystals.
- Plasmonic devices and metamaterials.
- Forces in the nano-world (light pressure and Casimir force).

Content

Research on nanostructures has revolutionised the field of optics and optical devices. This course will focus on unique optical properties of structures with dimensions smaller than the optical wavelength. From the fundamental principles to the latest advances in research, the course will explore light-matter interactions on the nano-meter scale, size effects in small objects and the use of nano-structures in modern optical devices.

Review of classical light-matter interaction

- Review of classical optical processes – macroscopic description
- Optical constants of materials
- Boundary conditions
- Plane wave propagation
- Refraction, reflection and transmission of optical waves
- Propagation of light in dense optical medium – introduction to microscopic models
- Dipole Oscillator Model
- Dispersion and absorption

Review of quantum theory of light and semi-classical light-matter interaction

- Review of quantum-mechanical treatment of photons and electrons
- Photon energy and momentum
- Free electrons: energy and momentum
- Electron-photon scattering – Compton effect
- Electrons in atoms
- Absorption and emission of photons by a quantum system

- Selection rules
- Statistical properties of particles
- Statistical distributions
- Bosons and fermions
- Density of states

Nano-scale microscopy
- Angular spectrum representation of optical fields
- Far-field propagating and near-field evanescent components
- Diffraction-limited spatial resolution in optical imaging
- Focusing of optical beams (Gaussian beam model)
- Optical fields near the focal point, resolution limits
- Increasing resolution with far-field methods
- Solid-immersion lens imaging, confocal microscopy, multi-photon microscopy
- Principle of near-field microscopy
- Information transfer from near-field to far-field
- Illumination and collection modes, imaging resolution
- Near-field probes
- Sub-wavelength aperture, metallic and dielectric tips

Forces at nano-scale
- Light pressure
- Electro-magnetic wave energy, pointing vector
- Photon energy and momentum
- Light pressure and interaction with dielectrics and metals
- Laser traps and optical tweezers
- The Casimir force
- Zero-field vacuum fluctuations
- Modes in a cavity
- Attractive force between two parallel plates
- Repulsive Casimir force

Semiconductor nanostructures
- Optical properties of semiconductors
- Optical properties of confined electronic systems
- Electronic states in reduced dimensions: particle in the box
- Dispersion relationships and density of states
- Semiconductor nanostructures: Quantum Wells and Quantum Dots
- III-V alloys and Quantum Well growth
- Self-consistent band structure diagrams
- Electron wavefunction
- Lateral confinement: lithographically-defined and self-assembled QDs
- Electronic excitations in quantum wells and quantum dots
- Confining potential and electronic ground and excited states
- Interband excitations (excitons)
- Selection rules

Resonators, micro-cavities and photonic crystals
- Optical field enhancement
- Modes in an optical resonator
- Mode spacing in low-dimensional structures
- Field enhancement
- Types of resonators

- Microcavity, pillar, disk and sphere
- Interaction of the cavity mode with electronic excitations
- Weak and strong coupling regimes
- Exciton-polariton
- Photonic crystals
- Photonic bandgap
- Planar photonic crystal waveguides; micro-structured fibre; photonic crystal lasers

Broadband Technologies and Components (BTC)

Location: UCL

Module code: ELEC0108

Module leader: Prof Cyril Renaud

Timing and structure: Term 1. Assessment: 100% exam.

Aims

This module introduces the technologies involved in the design and construction of transport networks (wireless, copper and optical) and the applications areas in which they are used.

Objectives

At the end of the course, students should be able to:

- Describe the operation of optical components such as lasers, receivers, optical amplifiers wavelength filters etc.
- Describe the elements required for the construction of optical, wireless and copper links in technical terms.
- Perform basic system design calculations for both optical (in terms of power and/or dispersion budget) and wireless systems (power budget) as well as consider to a first approximation the impact of noise.
- Appreciate the role of optical and wireless links in the construction of communications networks.

Content

This course covers the physical fundamentals of the generation, guided transmission, amplification and reception of light, the design consideration and techniques used in radio networks, the principles of digital transmission and the role of optics and wireless in both access and core networks.

This includes:

- Principles of digital transmission
- Optical fibre principles
- Principles of photon generation and reception
- Optical amplification and wavelength division multiplexing
- Design of optical links
- Optical networking
- Radio propagation
- Radio system concepts
- Microwave transmission systems

Broadband Communications Lab (BCL)

Location: UCL

Module code: ELEC0050

Module leader: Dr David Selviah

Timing and structure: Term 1. Assessment: 100% coursework.

Aims

Experimental and practical skills are an important part of the skill set of any Engineer. This course introduces students to state-of-the-art test and measurement equipment and techniques that are used in research and development laboratories around the world to characterise optical and RF devices and systems.

It provides students with hands on practical experience both with the devices themselves and the measurement equipment required to characterise their performance via a series of laboratory sessions.

Student will gain familiarity with the operation of several types of advanced photonic and RF devices and learn good experimental technique in optical and RF measurement procedures.

Objectives

By the end of the course students should be able to:

- Operate a modern fibre splicer and splice optical fibres.
- Set up a simple optical transmission link model and perform simulation in OPTSIM.
- Set up a microwave signal generator and spectrum analyser correctly for measuring the frequency response, gain, noise figure, 1-dB gain compression point and the two-tone third order intermodulation for a device-under-test (DUT) such as a microwave amplifier.
- Use a vector signal generator to generate a vector modulated wireless signal, e.g. 16QAM, and examine the received/amplified vector modulated wireless signal with a vector signal analyser.
- Explain how the non-ideal characteristics of an amplifier, e.g. noise figure and saturation, affect and distort the vector modulated wireless signals and relate the distorted constellation diagram and frequency spectrum back to the earlier analogue measurements.
- Calibrate a vector network analyser (VNA) using open, short, 50O and through standards for 1- port and 2-port scattering-parameter measurements.
- Set up a vector network analyser correctly to measure the reflection and transmission coefficients of a device-under-test as a function of frequency.
- Know the roles of the key components of a phase locked loop, i.e. the voltage controlled oscillator, frequency divider, loop filter, phase comparator and the reference oscillator.
- Characterise the voltage controlled oscillator with a spectrum analyser.
- Construct simple loop filters on a breadboard for a radio frequency phase locked loop and characterise how the filter bandwidths affect the frequency modulation response of the loop.
- Calibrate a light-wave component analyser (LCA) for E/E, E/O, O/E and O/O measurements.
- Set up a LCA correctly and perform direct intensity modulation for a DFB laser and measure its frequency response as a function of the bias current.
- Set up a LCA correctly to perform phase and delay measurements for a device-under-test

- Characterise the optical spectral of optical sources using an optical spectrum analyser and select the correct reference level and resolution bandwidth.
- Set up correctly a Bit Error Rate Analyser for assessing the performance of optical transmission link.
- Use the Bit Error Rate Analyser to measure and assess the eye diagram of the received optical signals in the presence of fibre chromatic dispersion, laser relative intensity noise, amplifier spontaneous emission noise, self- and cross-phase modulations, and four-wave mixing.

Content

The module centres around a range of structured optical and radio frequency practical laboratory experiments preceded by directed study material, including, lectures, videos and manufacturer datasheets and quizzes. In the laboratory, the students splice together two optical fibres and carry out a sequence of experiments following detailed written instructions, which they read before entering the laboratory.

Advice and help are provided by two PhD level demonstrators and an academic with technical support. This module provides practical demonstrations of material taught in lectures on optical and RF devices and systems or can be taken alone by PhD students or project students.

This includes:

- Safety in fibre optic installations, reading material, Fujikura splicing video, splicing quiz, calibration for vector network analysers
- Fibre splicing training
- Optical simulation with OPTSIM
- Optical spectrum analyser and characterisation of optical sources
- Lightwave component analyser and modulation response measurement of a DFB laser
- Bit error rate analyser and digital optical transmission measurement
- Vector signal generator and analyser and characterisation of microwave amplifier
- Vector network analyser and frequency response measurement for microwave filters
- Phase locked loop basics, loop filter design and frequency modulation characteristics

Applied Machine Learning Systems 1 – MSL1 (AML)

Location: UCL

Module code: ELEC0134

Module leader: Dr Miguel Rodrigues

Timing and structure: Term 1. Assessment: 100% coursework x 2 (5,000 words each).

Aims

This module aims to:

- Provide students with an introduction to the principles of machine learning engineering, covering topics such as supervised learning algorithms, unsupervised learning algorithms, and neural networks.
- Provide students with an introduction to the practice of machine learning engineering via a series of hands-on sessions.

Objectives

By the end of the module students are expected to:

- Appreciate the major technological developments in machine learning engineering, including its history to date.
- Understand general and specific ideas, methodologies, and algorithms in machine learning engineering, including supervised learning, unsupervised learning, and various learning algorithms.
- Understand how to apply machine learning techniques to solve particular real-world problems via a number of use-cases.

Content

This module covers basic principles and practice of machine learning systems engineering. In particular, the module will cover a wide range of topics such as introduction to machine learning engineering, supervised learning algorithms, unsupervised learning algorithms, kernel learning, and neural networks. The module encompasses a series of lectures as well as series of hands-on programming sessions, so that students can learn how to apply machine learning technology to address various data science problems.

Software for Network Services and Design (SNS)

Location: UCL

Module code: ELEC0088

Module leader: Prof Miguel Rio

Timing and structure: Term 1. Assessment: 100% coursework. The module is assessed through a set of coding and written assignments, some of which will be carried out during the module.

Aims

This course will provide an introduction to Object Oriented Programming and the Java programming language. It will have a big emphasis on network programming using the socket paradigm. There will also be an introduction to software engineering techniques and to UML.

Objectives

By the end of the course, students should be able to:

- Code simple programs in Java.
- Build client/server applications using TCP sockets.
- Build UDP based socket programs.
- Know the basic Software Engineering methods.
- Know how to specify a distributed application in UML.
- Know how to build an application for the Android platform.

Content

This course is primarily experiential in character. Lectures, hands-on activities and demonstrations are combined to provide exposure to, and experience of, a range of software skills appropriate to communication engineering, specifically addressing the increasingly important role of object oriented (OO) software techniques in telecommunications.

This includes:

- Introduction to Java
- Class Library Socket Network
- Programming Advanced
- Network Programming
- Software Engineering
- Techniques UML – Unified
- Modelling Language

Internet of Things (IOT)

Location: UCL

Module code: ELEC0130

Lecturer: Dr Ryan Grammenos

Timing and structure: Term 2. Assessment: 100% coursework (3,000 words).

Aims

This course is designed to provide an introduction to the Internet of Things (IoT) for postgraduate students who already have a background in electronic engineering or a related subject, an understanding of basic networking and some software (coding) experience. The course is designed to give the students a solid grounding of the key technologies involved and how they are integrated to form complete IoT systems. We also aim to give students an understanding of how the internet of things fits within the wider context of the ICT industry.

Objectives

At the end of the module students should be able to:

- Design an end to end connected system using appropriate and optimal technologies.
- Specify technologies required to meet a design requirement.
- Evaluate standards, propriety systems and published research to determine design solutions.

Content

This module looks at the networks and network technologies that form the basis of connected systems. It looks in more detail at how both wireless and optical networks are designed and constructed and how these form the backbone of communications systems including the internet. The module aims to discuss in detail the key technologies require to construct connected systems and Internet of Things devices and applications.

It covers the main technologies and design considerations, including in depth coverage of:

- Physical layer systems
- Real-time operating systems
- MAC layer issues
- Sensor node architectures
- Synchronisation and energy consumption issues
- IP/MQTT Protocols
- Security, reliability, privacy and authentication
- Applications and cloud processing

Business module

15 credits, choose 1

Telecommunications Business Environment (TBE)

Location: UCL

Module code: ELEC0094

Lecturer: Dr Clive Poole

Timing and structure: Term 2. Assessment: 100% coursework.

Following the laboratory sessions the students write two reports on the experiments that they have performed and the computer modelling simulations that they have carried out: The Optical Device Characterisation Report and the RF Device Characterisation Report, which are submitted on Moodle software and marked by academics. The marks for the two reports carry the full 100% coursework mark available for the module.

Aims

The aims of this module are for students to gain an appreciation of the external environment within which a telecommunications business operates and how a company can successfully conduct business in this environment. Two perspectives are taken: scene setting descriptions of the macro-economic and regulatory environment of today (UK and global view); coupled with an introduction to the management of a telecommunications business. Emphasis is on providing an understanding of the interactive nature of the forces impacting on the performance of Telcos.

Objectives

At the end of the course, students should be able to understand:

- Value Chain analysis, the detailed ICT Value Chain and the position of telecommunications operators within it.
- The Macro-economic environment including regulation, global trends and changing customer needs/expectations.
- How to develop winning strategies in this environment.
- The key elements of successful trading, including strategy development, customer service, technology developments and exploitation and portfolio and product development.
- The key elements of successful product and portfolio management and how to apply them in a changing world.
- How to use systems and technological developments to meet customer needs and improve customer service.
- Risk evaluation and mitigating strategies.

Content

Introduction to telecommunications and ICT business
Scene setting for today's business: covering the types of network operator and the range of competitors. The concept of ICT is defined, together with the convergence issues. This set of lectures will position the interaction of all the factors affecting an operator: macro-economic, the market place, government policy, regulation, competition, legacy aspects and technology changes, customer expectation and globalisation. The dotcom bubble burst will be examined for lessons for today's business environment.

Business strategic drivers
The concept of strategy is introduced and applied to a network operator (fixed, mobile, voice and data). The various strategy analysis tools (PEST, PUV, Porters 5 Forces, and SWOT) are introduced and example strategies discussed.

The regulatory and legal scene
The UK, and European legal and regulatory framework is presented, showing the constraints and opportunities offered to incumbent and other operators and service providers. Apart from interconnect issues, the Telecommunications Strategic Review is described, as is the role of OFCOM in regulating in a converged world.

Review of the industry
This section presents a quantified view of the industry from a world-wide perspective. The major cost, revenue, demand, service and technology trends are analysed.

Infrastructure economics
Description of the cost dynamics of a telecommunications infrastructure, covering access and core – fundamental to all networks (including railways, airlines, electricity supply, etc.), fixed and variable cost, effect of volume on unit cost, cost and revenue apportionment, and long-run costs.

Product management and marketing
An overview of the principles of marketing and product management is presented, together with recent practical examples. The scope includes: market segmentation, pricing, promotion, sales strategies, customer-relationship management, billing issues and product/service development. In particular, the product life cycle is used as a structure to consider all aspects of product/service management. Although these principles are generic, the examples given will relate specifically to the telecommunications industry.

Business cases
The key aspects of a business case are introduced, covering its role in corporate governance, the essential content, the financial case and supporting evidence.

Financial management
The role of financial management in any business is described, with detailed application to the telecommunications network operators' functions. Students will gain an understanding of financial statements and how to read them, as well as the principles of amortisation and depreciation, ebitda, profit, cash flow, cost of capital, share price dynamics and dividend policy.

Management of Technology (M&T)

Location: University of Cambridge

Module code: UCAM-4E4

Lecturers: Prof Tim Minshall, Dr Letizia Mortara, Dr Clive Kerr, Prof Rick Mitchell, Dr Rob Phaal

Timing and structure: Michaelmas term. Eight 2-hour sessions incorporating industry speakers. Assessment: 100% coursework.

Aims

The aims of the course are to:

- Provide students with an understanding of the ways in which technology is brought to market by focusing on key technology management topics from the standpoint of an established business as well as new entrepreneurial ventures.
- Place emphasis on frameworks and methods that are both theoretically sound and practically useful.
- Provide students with both an understanding of the issues and the practical means of dealing with them in an engineering context.

Objectives

By the end of the course students should be able to:

- Have a thorough appreciation of how technology is brought to address market opportunities, and how technology management supports that process.
- Assess and utilise appropriate technology management methods in different contexts.
- Understand the core issues of technology management and the practical means of dealing with them in an engineering context.

Content

Introduction: Technology in the business context

- Technology origins and evolution
- How technology generates value
- What are technology management processes and how are they used?

Developing new technologies: Managing research and development (R&D) and intellectual property rights (IPR)

- How do you manage a portfolio of R&D projects?
- What are the key aspects of IPR and how are they managed?
- How do you put a value on R&D projects and IPR?

Making money from new technologies: How to choose the right business model

- What are the different ways in which an idea can be brought to market?
- Why do most innovations reach the market through new firms rather than established firms?
- How do new and established firms work together?

Resources to bring ideas to market: 'Make versus Buy' (MvB) and strategic alliances

- Strategic context for MvB and partnering decisions
- Tools and techniques to support MvB decisions
- Working in partnership with other organisations

Open approaches to innovation

- Why open approaches have become very common
- What are the different types of open innovation?
- What are the challenges in managing open models of innovation?

New product introduction (NPI)

- Structuring the NPI process
- New product life cycles, time-to-market and metrics
- Completing an NPI project on time and within budget

Planning for the future: Technology strategy and planning

- Strategic technology management
- Planning for the future by linking technology, product and market considerations - Technology Road Mapping (TRM)
- Scenario planning tools to help manage the uncertainties of the future

Technology management in practice

- A panel of experienced technology managers will share lessons, and respond to queries posed by students

Coursework

For the coursework, students are required to research and write a report of approximately 3,000 words on a specific management of technology theme provided in the first lecture of the module. The report should draw upon module material supplemented with students' own research on both industrial practice and academic theory.

Mini-projects
45 credits each, compulsory

Mini Project 1
Code: ELEC0080

Timing: part-time, October – May.

Assessment: written report and oral presentation

Mini Project 2
Code: ELEC0079

Timing: full-time, May – August.

Assessment: written report

Generic skills development
Attendance required

Transferrable skills: Responsible Innovation workshop
(Required for UCL registered students)

Code: ELEC0052

Timing: terms 1 and 2

Module leader: Dr Miguel Rodrigues

Assessment: 100% exam. 15 credits.

Research Development Course (RDC)
(Required for Cambridge registered students)

Location: University of Cambridge

Module leader: Dr Hannah Joyce

Timing and structure: most groups meet once a week during term-time. 15 credits.

Aims: The aim if this programme is to help you develop the skills you need for your MRes year assessments and successful completion of your PhD (e.g. writing and presenting your research).

A wide variety of research skills and professional development activities and workshops are provided by the Department of Engineering, the School of Technology and the University, such as:

- How to write a first-year report
- How to be an effective researcher
- Planning your personal skills development
- Making the most of your presentation

Seminars and events

Attendance required

CDT Seminar series

Timing: monthly, November to July

Location: alternates between UCL and University of Cambridge

Overview

The CDT Seminar series runs monthly from November to July. All CEPS and IPES CDT students are required to attend. An attendance register is taken.

At each seminar one or two PhD students from the photonics CDT will present their research followed by a short question and answer session. We also invite speakers from industry and other fields of research to present to facilitate broader, cross-discipline learning.

Aims

The aims of the seminar series are to:

- Enable students to practice presentation skills and check that their research is on track.
- Encourage and provide peer-to-peer learning, review and feedback.
- Learn from industry speakers.
- Learn from other areas of research that can contribute to your work.

Students are encouraged to ask questions to gain a broader knowledge of the rapidly emerging field of connected electronic and photonic systems.

Industry Day, CEPS CDT

Timing: annually, date TBC

Location: alternates between UCL and University of Cambridge

The photonics CDT hosts an annual Industry Day; a full-day event that brings together industry partners, CDT students and academics to discuss our cutting-edge research as well as opportunities for collaboration in the field of photonics.

This is a fantastic opportunity for students to meet key people within the industry and talk about current projects, future research ambitions and career opportunities.

CDT PhD students are required to display a research poster at the event. Posters are optional for MRes students.

The Barlow Memorial Lecture and research poster presentation

Timing: biennially (last held 2019), normally in May or June

Location: UCL, Department of Electronic and Electrical Engineering (EEE)

Overview

The Barlow Memorial Lecture is held in memory of Harold Everard Monteagle Barlow (1899-1989) who was the Head of the Department of Electronic and Electrical Engineering at UCL from 1950 to 1967. He invented the H01 millimetre waveguide and is remembered for his many contributions to microwave research.

At the event we celebrate the current research of the EEE Department with a research poster display showcasing the work of UCL staff, Masters, PhD and EngD researchers.

CDT students are strongly encouraged to display a research poster at the event.

Prizes are awarded for the best research posters in different categories.

https://www.ee.ucl.ac.uk/barlow