IMPERIAL

Module Specification

Basic details

UID		Cohorts covered	Earliest cohort: / Latest c
Long title	Advanced Communication Theory		
New code	ELEC70045	New short title	

Brief description of module *(approx. 600 chars.)*

Building on foundational communications theory, this module introduces advanced, state-of-the-art topics in antenna array–based wireless communication systems, including MIMO, beamforming, array manifolds, and channel modelling. It covers key concepts underpinning modern and next-generation networks (5G and beyond), such as massive MIMO, beyond-massive-MIMO architectures, integrated spatio-temporal signal processing, and detection/estimation techniques. The module provides a rigorous understanding of space-time wireless system design, analysis, and performance evaluation.

579 characters

Available as a standalone module/ short course? No

Statutory details

	ECTS	CATS	Non-credit
Credit value	5	10	N
FHEQ level	L7		

HECOS codes:

Allocation of study hours

	Hours	
Lectures	20	
Group teaching	10	*Incl. seminars, tutorials, problem classes.*
Lab/ practical	0	
Other scheduled	0	*Incl. project supervision, fieldwork, external visits.*
Independent study	95	*Incl. wider reading/ practice, follow-up work, completion of assessment*
Placement	0	*Incl. work-based learning and study that occurs overseas.*
Total hours	125	
ECTS ratio	25.00	

Project/placement activity

Is placement activity allowed? No

Module delivery

Delivery mode	Taught/ Campus	Other	
Delivery term	Term 1	Other	

Ownership

Primary department: Department of Electrical and Electronic Engineering

Additional teaching departments: 0

Delivery campus	South Kensington

Collaborative delivery

Collaborative delivery?	0
External institution	
External department	
External campus	

Associated staff

Role	CID	Given name	Surname
Module Leader		Athanassios	Manikas
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Learning and teaching

Module description

Learning outcomes

Upon completion of this module, you will be able to:
(1) design and analyse optimum receivers using decision theory;
(2) model and evaluate diversity systems;
(3) analyse SIMO, MISO, and MIMO multi-antenna systems;
(4) formulate and solve detection, estimation, and reception problems for array receivers;
(5) model advanced architectures including massive MIMO and mmWave communications; and
(6) design and evaluate localisation algorithms (TOA, TDOA, RSSI, DOA, fingerprinting).

Module content

1. INTRODUCTORY CONCEPTS: Modelling of information sources, communication channels and sinks. Parametric and non-parametric multi-antenna models. Definitions of priori and posterior probabilities in relation to the model of a communication channel. MAP criterion, likelihood functions and likelihood ratio. Basic SISO, SIMO, MISO and MIMO communication system architectures. Structure of the Array Manifold vector. Common symbols and notation.
2. PRINCIPLES OF DIVERSITY THEORY: Definitions, diversity combining rules, classification of diversity systems (space, time, frequency, multipath) and examples. Emphasis is given on multipath diversity (Rayleigh fading, fading margins, and diversity gain). Optimum diversity theory and performance analysis.
3. SIMO, MISO & MIMO ANTENNA ARRAY COMMUNICATIONS: multi-antenna wireless channel analysis, space selectivity, scattering function, impulse response, single-path and multipath SIMO/MISO/MIMO models. Multipath clustering and virtual MIMO antenna array systems. Channel capacity analysis for multi-antenna configurations.
4. ARRAY RECEIVERS for SIMO & MIMO: Description of the theory for solving the following three general problems
A.Detection Problem detecting multiple transmitters transmitting simultaneously at the same frequency band (M-ary detection, matched filter receivers).
B.Channel Estimation Problem Multi-parameter channel estimators of the desired user/source - including Directions of Arrival (DOA), powers, cross-correlations etc. for both frequency selective and frequency flat channels
C.Reception Problem
Emphasis on antenna array patterns and beamformers (space and spatiotemporal beamformers). Design of optimum receivers (including multipaths, angular spread, Doppler spread and fading). Evaluation of performance criteria (outage probability, output SNIR,

	5. EXTENDED SYSTEM ARCHITECTURES: Systems with increased degrees of freedom - Massive Systems (maMI, maSi, maMISO), mmWave Communications, Spatiotemporal Wireless Communications. Discussion of channel models, hardware constraints, and signal processing challenges for 5G and beyond (5G+). 6. LOCALISATION OF WIRELESS SIGNALS: Classification of localisation systems and architectures (self-positioning, remote positioning, infrastructure-based). Detailed study of localisation algorithms: TOA (Time of Arrival), TDOA (Time Difference of Arrival), RSSI (Received Signal Strength Indication), DOA-localisation (Direction of Arrival), LAA (Location Aided Algorithms), Hybrid localisation, and Fingerprinting. Identification and analysis of primary sources of error (e.g., multipath, non-line-of-sight, thermal noise, synchronisation errors).
Learning and Teaching Approach	The module employs an integrated learning and teaching strategy that combines formal lectures, interactive problem-solving classes, and guided independent study to effectively deliver the advanced theoretical and practical content. **Lectures (20 hours):** The lectures systematically deliver the core theoretical frameworks—spanning decision theory, diversity theory, array signal processing, MIMO channel modelling, advanced 5G+ architectures (massive MIMO, mmWave), and localisation algorithms. Each session combines rigorous mathematical derivations with system-level illustrations and real-world wireless communication examples, ensuring students develop both the analytical tools and the intuitive understanding required for cutting-edge research and industry applications. **Problem-Solving Classes (10 hours):** These interactive small-group sessions provide a collaborative environment where students apply lecture theories to numerical and analytical problems. These classes are structured to bridge theory and practice, reinforcing conceptual understanding while directly preparing students for the coursework and summative MCQ examination through guided practice of typical exam-style questions. **Technology-Enhanced Learning:** A shared OneNote Class Notebook serves as the central digital hub for the module. It hosts all lecture materials, annotated slides, worked solutions to problem sheets, and supplementary resources. Crucially, it also provides an asynchronous discussion forum for peer-to-peer support, staff Q&A, and collaborative problem-solving, ensuring continuous engagement and accessibility outside of scheduled contact hours. **Support for Coursework (Summative):** The two summative coursework components—a communications system simulation (Coursework A) and a wireless localisation project (Coursework B)—are introduced during lectures and further supported via dedicated problem-solving sessions. This enables students to translate abstract theoretical concepts (e.g., array receivers, beamforming, TOA/TDOA/DOA algorithms) into practical MATLAB-based implementations, fostering essential research and coding skills. **Guided Independent Study (95 hours):** Students are expected to consolidate their learning through extensive independent study, including reviewing lecture notes, completing weekly problem sheets, engaging with the provided reading list (including the core textbook and research papers), and undertaking background reading to contextualise emerging topics such as massive MIMO, mmWave communications, and 5G+ systems. The structured problem

Assessment Strategy

Assessed Components:

1. Examination (50%): A multiple-choice question (MCQ) based examination. This tests students' breadth of knowledge across all six topics, their ability to apply analytical techniques (e.g., likelihood ratio tests, diversity gain calculations, MIMO capacity, beamforming design), and their capacity for rapid problem-solving under timed conditions. The MCQ format ensures comprehensive coverage of the whole syllabus while allowing precise and objective marking. Assesses Learning Outcomes 1–6.

2. Coursework A – Spatiotemporal Array Communications: ST-System Design (35%): A practical MATLAB-based assignment requiring students to simulate and analyse a multi-antenna wireless communication system. This may include implementing an array receiver, evaluating diversity performance, or designing a beamformer for a SIMO/MIMO scenario. Students demonstrate their ability to translate theoretical concepts into working code, interpret simulation results, and produce a professional technical report. Assesses Learning Outcomes 1–5.

3. Coursework B – Wireless Localisation (15%): A focused assignment where students implement and evaluate one or more localisation algorithms (e.g., TOA, TDOA, RSSI, DOA, or fingerprinting) in MATLAB. Students analyse the performance of their algorithm under various conditions (e.g., noise, multipath, NLOS) and critically assess sources of error. This component develops skills in algorithm design, data analysis, and critical evaluation. Assesses Learning Outcome 6.

Practice and Preparation:
• **Two Practice MCQ Tests:** Embedded at strategic points in the teaching schedule (typically after Topics 1–3 and Topics 4–6). These low-stakes tests simulate the exam format, allowing students to self-assess their progress, identify areas requiring further study, and familiarise themselves with the MCQ style well before the final examination.

Feedback

The module provides comprehensive and timely feedback to support student learning and development throughout the term.

Practice MCQ Tests: Students receive automated feedback immediately upon completion, indicating correct/incorrect answers with brief explanations for each question. This enables rapid identification of misconceptions and targeted revision.

Problem-Solving Classes: During interactive sessions, students receive verbal and written feedback from the lecturer and teaching assistants on their approach to analytical and numerical problems. This direct interaction allows for immediate clarification of difficult concepts.

Coursework A (Spatiotemporal Array Communications: ST-System Design): Students receive detailed written feedback on their design, submitted MATLAB code and technical report.

Coursework B (Wireless Localisation): Written feedback is provided on the algorithm implementation, performance analysis, and critical evaluation of errors. Students are given clear guidance on strengths and areas for improvement.

Examination: While individual question-level feedback is not provided for the MCQ examination, cohort-level feedback is shared via the OneNote Class Notebook, indicating overall performance trends, commonly misunderstood topics, and areas where the cohort excelled or struggled. This supports future cohorts and provides context for individual

Reading list

The reading list is curated to support both the theoretical depth and practical application required for the module. It comprises a core textbook, a specialised application required for the module. It comprises a core textbook, a specialised research monograph, additional reference texts, and digital resources.

[1] D. Tse and P. Viswanath, Fundamentals of Wireless Communication, Cambridge University Press, 2005. [Comprehensive coverage of wireless channel models, capacity, diversity, and MIMO systems. Essential for Topics 2, 3, and 4.]

[2] A. Manikas, Differential Geometry in Array Processing, Imperial College Press, 2004 (selected chapters). [Advanced treatment of array manifold structures, differential geometry, and array processing. Essential for Topics 4 and 5.]

[3] A. Manikas, "Interference Cancellation Techniques Experiment", available at: http://skynet.ee.ic.ac.uk/am1.zip. [MATLAB-based practical resources supporting coursework and simulation-based learning.]

[4] A. Goldsmith, Wireless Communications, Cambridge University Press, 2005. [Excellent supplementary text providing broader context and alternative explanations of key concepts.]

[5] H. L. Van Trees, Detection, Estimation, and Modulation Theory, Part I, Wiley, 2001. [Foundational text on decision theory and detection/estimation. Recommended for deeper study of Topic 4.]

[6] E. Biglieri, R. Calderbank, A. Constantinides, A. Goldsmith, A. Paulraj, and H. V. Poor, MIMO Wireless Communications, Cambridge University Press, 2007.

[7] S. Haykin, Adaptive Filter Theory, Prentice Hall, 5th Edition, 2014. [For advanced study of beamforming and adaptive array processing.]

Main Resources:

Quality assurance

Date of first approval	
Date of last revision	June 2026
Date of this approval	
Module leader	Professor Athanassios Manikas
Notes/ comments	

Office use only

QA Lead	
Department staff	
Date of collection	
Date exported	
Date imported	

Template version #####

Assessment details

Grading method	Numerical	Pass mark	50%

Assessments

Assessment type	Assessment description	Weighting	Pass mark	Must pass?
Examination	Multiple-choice question written paper	50%	50%	N
Coursework	Coursework part A: Simulation of a communications system	35%	50%	N
Coursework	Coursework part B: localisation of wireless signals	15%	50%	N
0	0	0%	0%	0.00
0	0	0%	0%	0.00
0	0	0%	0%	0.00
0	0	0%	0%	0.00
0	0	0%	0%	0.00
0	0	0%	0%	0.00
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0	0	0%	0%	0.00
0	0	0%	0%	0.00
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