OUTLINE:
First Semester M2 ROSP

- Refresher: 2 elective courses to be chosen

<table>
<thead>
<tr>
<th>Blocks</th>
<th>Ects</th>
<th>Cours</th>
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<th>TP</th>
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<tr>
<td>Refresher: Physics of Optoelectronic Devices</td>
<td>2</td>
<td>10h</td>
<td>3h</td>
<td>6h</td>
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<tr>
<td>Refresher: Communication Networks</td>
<td>2</td>
<td>15h</td>
<td>3h</td>
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<tr>
<td>Refresher: Digital Communications</td>
<td>2</td>
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- Core courses

<table>
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<tr>
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<tr>
<td>Digital Information Processing</td>
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<td>24h</td>
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<td>Error-Correcting Codes and Coded Modulations Applied to Optical Communications</td>
<td>2</td>
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<td>Optical Information Propagation and Point-to-Point Transmission Systems</td>
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<td>Future Trends in Optical Networks</td>
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<td>6h</td>
<td>3h</td>
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<td>Photonic Systems Towards Other Applications</td>
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- 1 elective course to be chosen

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<thead>
<tr>
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Second Semester ROSP

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DETAILED VERSIONS of each block contents
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Refresher: Physics of Optoelectronic Devices

ECTS
2
Mots clés
Description du contenu de l'enseignement
Syllabus - Basics of semiconductor physics: energy bands; Fermi-Dirac distribution; difference between conductors, insulators, semi-conductors; doping
- Basics of lasers: black-body radiation; self-oscillation conditions; resonant cavities
- Semiconductor lasers: Bernard & Duraffourg condition; structures (Fabry-Perot, DFB); gain curve; evolution equations
- Electro-optical modulation: phase and Mach-Zehnder intensity modulators; electro-absorption
- Propagation in a dielectric waveguide: the optical fibre (modes, dispersion, attenuation)
- Optical signal detection and noise, amplified systems
Compétences à acquérir
List the basic concepts underlying opto-electronic devices and guided propagation
Explain their physical principles
Specify the characteristics of these devices that are critical to their use in optical transmission systems
Modalités d'organisation et de suivi
Professor in charge:
Cédric Ware, Associate Professor, TELECOM Paris
Langue
Anglais
Volume horaire
CM: 10h, TP: 6h, TD: 3h
Mode de contrôle des connaissances
Project (80%), Lab work scores (20%)

Refresher: Communication Networks
ECTS
2
Mots clés
Description du contenu de l'enseignement
Description General introduction to Networking, with a special focus on current network architectures and the specificities of optical networks.
Syllabus Global network architecture
IP networks
SDH networks
Mobile network architecture
Modalités d'organisation et de suivi
Professors in charge:
Mounia Lourdiane, Associate Professor, TELECOM SudParis
Cédric Ware, Associate Professor, TELECOM Paris
Langue
Anglais
Volume horaire
CM: 15h, TD: 3h
Mode de contrôle des connaissances
Final exam

Refresher: Digital Communications
ECTS
2
Course Objectives:
The objective of this refresher course is to provide the fundamentals tools of digital communications in the simplest case given by the Additive White Gaussian Noise channel.

Syllabus
• Additive White Gaussian Noise (AWGN) model
• Detection theory: MAP and ML detector
• Matched filter, Threshold detector
• Inter-Symbol Interference (ISI), Nyquist criterion
• Bit error rate, minimal distance, performance
• Block Forward Error Correcting codes (FEC), Coding gain

Compétences à acquérir
On completion of the course students should be able to:
• design an optimal coherent receiver
• know the relationship between fundamentals parameters (such as bandwidth, power, etc)
• understand the principle of an error correcting codes

Modalités d'organisation et de suivi
Professor in charge:
Ghaya Rekaya-Ben Othman, Professor, TELECOM Paris
Hadi Ghauch, Associate Professor, TELECOM Paris
Other teachers:
Antoine O. Berthet, Professor, CentraleSupélec

Langue
Anglais
Volume horaire
CM : 20h
Bibliographie, lectures recommandées
D. Tse, “Fundamentals of wireless communications”.
A. Goldsmith, “Wireless communications”.
J. Proakis, “Digital communications”.

Pré-requis obligatoires
Course Prerequisites:
• Introduction to digital communications (modulation BPSK, threshold detector)
• Introduction to statistics (random variable, random stationary process)

Mode de contrôle des connaissances
Final exam

Optoelectronic Devices
ECTS
4
Mots clés
Compétences à acquérir
- Derive laser oscillation equations and evolution equations for charge carriers and photons
- Explain the physical principles underlying semiconductor lasers
- List the common cavity structures used in laser design and describe their spectral response
- List the different classes of electro-optical modulators used in optical communication systems
- Explain each class’ typical response in terms of linearity, bandwidth, phase-amplitude coupling
- Describe the main optoelectronic receiver types and their typical performances
- Derive wave guiding conditions in a dielectric waveguide, list mode categories, calculate the number of guided modes in a step-index planar structure
- Characterise the first few modes of an optical fibre; derive mode-coupling equations in a simple case (directional coupler or Bragg coupler)
- Acquire a strong knowledge of semiconductor laser dynamics; grasp nonlinear problematics and apply them to future communication systems
- Acquire knowledge of inter-sub-band devices. Explain the main differences between inter-band and inter-sub-band lasers. Acquire strong knowledge of applications, fabrication techniques, pros and cons of inter-sub-band devices

Modalités d'organisation et de suivi
Professors in charge:
Adel Bousseksou, Associate professor, Université Paris-Sud
Cédric Ware, Professor, TELECOM Paris

Langue
Anglais

Volume horaire
CM : 29h, TP : 4h, TD : 5h

Mode de contrôle des connaissances
Final exam, Lab work scores, Project

Digital Information Processing
ECTS
3

Mots clés

Description du contenu de l'enseignement

Course Objectives:
The objectives of the course are to introduce the main solutions coming from digital communications and signal processing to improve the quality of the optical fiber based transmission.

Syllabus:
• Optical fiber model (CD, PMP, PDL, PDM, nonlinearity based Volterra series) with a digital communications point-of-view, Differences with wireless links
• Fundamental limits thorough information theory tools: Shannon capacity and interpretation
• Detection theory (MAP, ML)
• Intersymbol interference mitigation
  – Viterbi algorithm
  – Linear and nonlinear equalization (ZF, MMSE, DFE) and application to optical fiber.
  – What can you do with Channel State Information at the Transmitter (CSIT): predistorsion.
• OFDM and related detection
• Nonlinear processing based on inverse Volterra series and receiver architecture
• MIMO processing and polar-time coding
  – Blind equalization (CMA) : block and adaptive version
  – Polar-time coding and related metrics (rate, etc)
• Alamouti code, Blast, Golden code and related performance, code design criterion
• Multi-mode, multi-core based communications
• Modulation and Coding Scheme selection with CSIT or partial side information
• Frequency and Phase synchronization

Compétences à acquérir
On completion of the course students should be able to:
• understand the influence of design paramters
• understand the influence of fiber impairments on theoretical and practical performance
• understand the main techniques improving the performance and select them in a smart way

Modalités d'organisation et de suivi
Professor in charge:
Ghaya Rekaya-Ben Othman, Professor, TELECOM Paris

Other teachers:
Philippe Ciblat, Professor, TELECOM Paris

Langue
Anglais
**Volume horaire**
CM : 24h, TP : 3h, TD : 3h

**Bibliographie, lectures recommandées**
D. Tse, “Fundamentals of wireless communications”.
A. Goldsmith, “Wireless communications”.
J. Proakis, “Digital communications”.

**Pré-requis obligatoires**
Course Prerequisites:
- Refresher course on digital communications
- Course on point-to-point optical transmission systems (propagation part)

**Mode de contrôle des connaissances**
Final exam

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**Error-Correcting Codes and Coded Modulations Applied to Optical Communications**

**ECTS**
2

**Mots clés**

**Description du contenu de l’enseignement**

**Course Objectives:**
- Understand the basics of algebraic coding and decoding
- Understand the basics of modern coding theory and the associated probabilistic decoding
- Comprehend the performance evaluation techniques of error correcting codes

**Syllabus**

**Chapter 1: Introduction to algebraic coding and finite fields (3h - lecture)**
- Bloc codes: generator and parity matrices
- Syndrome decoding
- Families of algebraic block codes

**Chapter 2: Finite fields**
- Construction of Galois fields
- Operations in a Galois field (addition, multiplication, division)
- Minimal polynomial

**Chapter 3: Algebraic codes and their decoding**
- Cyclic codes and their encoding using the generating polynomial
- Classes of cyclic codes: BCH and Reed-Solomon codes
- Decoding algorithms: Peterson, Forney, Euclidian, Berlekamp-Massey
- Performance bounds

**Chapter 4: Factor graphs and the sum-product algorithm**
- Definition of a factor graph
- Computation of marginal probabilities using the sum-product algorithm
- Correctness of the sum-product algorithm on an acyclic graph
- Performances of the sum-product algorithm for decoding block codes

**Chapter 5: LDPC codes: definition, construction and decoding**
- Construction of regular LDPC codes
- Tanner graphs and the sum-product algorithm for decoding LDPC codes
- Complexity reduction techniques

**Chapter 6: Performance analysis of LDPC codes**
- Weight enumerating functions of ensembles of codes
- Upper bounds on the performances of ensembles of codes
- Convergence analysis of sum-product decoding (density evolution, EXIT charts)
- Codes optimization techniques for irregular and generalized LDPC codes

**Compétences à acquérir**
On completion of the course students should be able to:
- Parameterize an error correcting code according to Shannon’s channel coding theorem
- Implement a codec for algebraic or LDPC codes
- Evaluate the performances of error correcting codes in the context of optical communications

Modalités d'organisation et de suivi

Professors in charge:
Frederic Lehmann, Associate professor, TELECOM SudParis
Antoine O. Berthet, Professor, CentraleSupélec

Langue
Anglais

Volume horaire
CM : 15.5h, TP : 3h, TD : 1.5h

Bibliographie, lectures recommandées

Pré-requis obligatoires
M1 level course in Information Theory
M1 level course in Digital Communications

Mode de contrôle des connaissances
Written examination

Optical Information Propagation and Point-to-Point Transmission Systems

ECTS
3

Mots clés

Description du contenu de l'enseignement

Course Objectives:
From a capacity, distance and cost need, know how to design an adequate point-to-point transmission system, using high spectral efficiency modulation formats and counteracting long-haul optical propagation impairments.

Syllabus :
• Chapter 1 : Overview of an optical transmission system setup
  Historical evolution of fiber optic transmission, growth of the need for capacity, review of technology breakthrough. Transmission setup from transmitter to receiver. Wavelength Division Multiplexing (WDM) principle. Optical amplification and Optical Signal-to-Noise Ratio (OSNR). Transmission system types from access to submarine ones. Transmission quality criteria.
• Chapter 2 : Transmitter and Receiver design
  Design of transmitters, laser sources, direct or external modulation, modulators setup and driving, modulation format implementations. Design of receivers, optical filter, photodiodes, noises, direct or coherent detection. OSNR receiver sensitivity for different modulation formats.
• Chapter 3 : Optical propagation in fibers
  Physical constraints of single channel signal propagation, linear effects (loss, dispersion and Polarization Mode Dispersion) , nonlinear effects (Kerr, Raman, Brillouin). Physical constraints of WDM transmission, dispersion wavelength dependency, amplification bands, linear and nonlinear cross-talks. Additional cumulative Amplified Spontaneous Emission (ASE) noise. Transmission modeling, temporal and spectral representation of signals, constellations, NonLinear Shrödinger Equation (NLSE) and numerical solving. Steps for designing transmission systems.
• Chapter 4 : Transverse view on new optical coherent transmission systems
**Compétences à acquérir**

On completion of the course students should be able to:
- **Objective 1**: Know and implement photonic devices and subsystems for transmissions.
- **Objective 2**: Design optical transmitter and receiver for all kind of modulation formats.
- **Objective 3**: Understand propagation signal impairments and know how to compensate or mitigate them.
- **Objective 4**: Find the cost effective transmission system design that answers a capacity and distance transmission requirement.

**Modalités d’organisation et de suivi**

Professor in charge:
Yann Frignac, Professor, TELECOM SudParis

Other teachers:
Yves Jaouen, Professor, TELECOM Paris

**Langue**

Anglais

**Volume horaire**

CM: 18h, TP: 12h

**Bibliographie, lectures recommandées**


**Pré-requis obligatoires**

Course Prerequisites:
- Waveguide optics, fibre optics and propagation modes.
- Light polarization, Jones, Stokes and Poincaré’s sphere, optical propagation in anisotropic media.
- Devices for photonic systems: laser, modulators, mux, photoreceivers, optical amplification and filters.
- Digital communication, Additive White Gaussian Noise channel, Nyquist criterium, pulse shaping and match filtering, complex modulation formats and Bit Error Probability estimations.

**Mode de contrôle des connaissances**

Final Exam, Lab work scores

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**Advanced and Next-Generation Optical Transmission Systems**

**ECTS**

2

**Mots clés**

Description du contenu de l’enseignement

**Course Objectives:**

Know the technologies that will supply extreme capacity demand while having the best energy efficiency. Advanced amplification techniques, future spatial multiplexing techniques, design and application of specialty fibers, tunable capacity transmitters and receivers. Acquire the ability of modeling transmission systems.

**Syllabus:**

- Chapter 1: Spatially multiplexed transmission systems
- Chapter 2: Advanced amplification schemes
• Chapter 3 : Next generation fibers
  FMF and MCF fiber for coupled or uncoupled SDM transmissions. Design and applications of Photonic
  Bandgap Fibers.
• Chapter 4 : Elastic transmitter and receivers
  Bit-rate adaptation for capacity demand, network routing constraints or energy saving. Superchannel
  concepts.
• Chapter 5 : Transmission systems modeling
  Optical transmission system simulation project.

Compétences à acquérir
On completion of the course students should be able to:
• Objective 1 : Understanding the challenges of Spatial Division Multiplexing techniques, new large-
  band amplification schemes and new fiber types.
• Objective 2 : Modeling transmission systems
• Objective 3 : Optimize cost and energy saving for high bit rate transmission systems.

Modalités d'organisation et de suivi
Professor in charge:
Mansoor Yousefi, Associate professor, TELECOM Paris

Other teachers:
Yann Frignac, Professor, TELECOM SudParis

Langue
Anglais
Volume horaire
CM : 12h, TP : 9h
Pré-requis obligatoires
Course Prerequisites:
• Optical information propagation and point-to-point transmission system (M2 module)
• Matlab programming.
• Spatial and Fourier optics.

Mode de contrôle des connaissances
Final Exam

Optical Networks
ECTS
4
Mots clés
Description du contenu de l'enseignement
Syllabus
- Wavelength-Division Multiplexing: evolution to IP-over-WDM from IP/SDH/WDM transmissions
- Flexible and elastic optical networks
- Access/metropolitan network, WDM-PONs
- Fixed-mobile convergence
- Student Micro-project

Compétences à acquérir
- Explain operator networks' global architectures, and specific issues of core, access and metropolitan
  networks
- Design parts of a global network in situations with specific constraints (traffic type, range, interoperability...)
- Explain the network evolution techniques described in the course, identify situations where they are
  relevant

Modalités d'organisation et de suivi
Professors in charge:
Mounia Lourdiane, Associate professor, TELECOM SudParis
Cédric Ware, Associate professor, TELECOM Paris
Future Trends in Optical Networks

ECTS
2

Mots clés

Description du contenu de l'enseignement

Syllabus - Switching packets in optical networks: OBS, OPS and OSS technologies
- Core/metropolitan network, P-OADM technology
- New energy-aware transparent node architectures
- New optical domestic network architectures

Modalités d'organisation et de suivi

Professors in charge:
Mounia Lourdiane, Associate professor, TELECOM SudParis
Cédric Ware, Associate professor, TELECOM Paris

Langue
Anglais

Volume horaire
CM : 9h, TP : 3h, TD : 6h

Mode de contrôle des connaissances
Project

Photonic Systems Towards Other Applications

ECTS
3

Mots clés

Description du contenu de l'enseignement

Abstract

This course illustrates the diversity of photonic system applications. The course will be based on optical labworks (18h) and short courses/conferences dedicated to various applications (12h).

Syllabus

Optical Labworks contents:
- Optical Time Domain Reflectometry
- Optical Fiber Gyrometer
- Slow and Fast Line in optical Fiber
- Nonlinear optics : Second Harmonic Generation, Raman Scatering in an optical Fiber

Short courses and Conferences (indicative list ):
- Photonic crystal fibers
- LiFi Technology
- Advanced signal processing for sensor applications
- Optical sensors technology
- ...

Modalités d'organisation et de suivi

Professor in charge:
Nicolas Dubreuil, Professor, IOGS
Fonction et intégration photonique

ECTS
3

Mots clés

Description du contenu de l'enseignement
Principes de fonctionnement et les technologies des dispositifs photoniques semi-conducteurs, dans une perspective d'intégration.

Compétences à acquérir
Principes de fonctionnement et les technologies des dispositifs photoniques semi-conducteurs, dans une perspective d'intégration.

Modalités d'organisation et de suivi

Henri Bénisty (IOGS)

Nanophotonics

ECTS
3

Mots clés

Description du contenu de l'enseignement

Objective:
The objective of this module is to train students in the fields of nanophotonics and its applications through the study of the properties of light propagation in nanostructured environments as well as the benefits from nanostructures for optoelectronics.

Outline:
- Photonic integrated circuits
  Properties of light waves
  Guiding, photonic integrated circuits : building blocs
  Example of application : silicon photonics
- Propagation of light in nanostructured environments
  Photonic crystals
  Plasmonics
  Metamaterial
- Photonics active devices
  Nanostructures for optoelectronics (quantum well, quantum dots, nanowires)
Compétences à acquérir
Abilaty to analyze and understand the challenges in photonics and nanophotonics. Be able to explain the basic phenomena in the field

Modalités d’organisation et de suivi
Professor in charge:
Delphine Marris-Morini, Professor, Université Paris-Sud

Langue
Anglais

Volume horaire
CM : 24h, TP : 3h

Pré-requis obligatoires
Basic knowledge of electromagnetism and semiconductor device physics

Mode de contrôle des connaissances
written test + report on the lab session

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Evaluation process :

The two semester do not compensate each other, average score has to be higher than 10/20 in each semester.
Score for each teaching block has to be higher than 7/20 to validate credits. Weighting coefficients applied to the block in the average score calculation corresponds to the amount of the block credits.

The following table gives details on the evaluation method for each block.

<table>
<thead>
<tr>
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<th>Note du bloc</th>
<th>Normalière</th>
<th>TP</th>
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<th>Note de contrôle des connaissances</th>
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<tr>
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END of DETAILED VERSIONS of each block contents

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