ENSSAT
LANNION

Master of Science in Photonics (M2) – International program in optical communications.

The master gathers forces from 6 universities and engineering schools on a common syllabus, with slight variations between institutions. The lectures are at ENSSAT.

Master – Semester 3: courses from September to January (>30 ECTS).

Constituent Course	Contact hours	ECTS
Laser Sources	24h	3
Integrated and Microwave Optics	24h	3
Optical amplification and nonlinear propagation	12h	3
Optical transmissions	12h	
Research Labworks	2 days/week	12
French as Foreign Language	30h	3

- Elective courses (up to 4)

Course Unit Name	Contact hours	ECTS
Practical work in photonics	24 h	3
Seminar in photonics by industrial and academic researchers	24 h	3
Advanced optical telecommunication systems	12 h	2
Laser noises	16 h	2
Summer School	24 h	2

Master – Semester 4: Research training (project) (30 ECTS).

The research project is spread along a year from beginning of July to the end of June. The research project is carried out at the Foton Institute- SP Team in the field of photonics. The project calendar is the following: full-time (July/August), 2 days/week (September -> mid-February), full-time (mid-February -> end of June)

Description of the courses:

Laser Sources (24h, 3 ECTS)

Introduction to semiconductor lasers – ENIB
Introduction to semiconductor lasers: Amplifying medium and cavity, bases for semiconductor media; Different types of structures, mono and multi-section lasers; Wavelength tunable structures; Modelling and parameters of semiconductor lasers; Modulation and control of dynamic properties; Association and integration with other structures, applications (clock recovery, fibre lasers).

Static and dynamic properties of laser sources – ENSSAT
Introduction to lasers; continuous operation; light modulation (external modulation, gain switching, Q-switch, dumping, saturable absorber, mode blocking, pulse lasers) and pulse engineering; optical injection, optical feedback; characterization of noise, intensity noise, frequency noise, coherence, metrology; a comparison of fiber lasers and semiconductor lasers; Example of sources for telecom applications, life sciences, environment, laser optical sensor.

Integrated and Microwave Optics (24h, 3 ECTS)

Integrated optics – INSA
1. The dielectric waveguide. Physics of planar dielectric waveguide by geometrical optics and electromagnetism. Introduction to 2D and 3D problem solving methods. Physics of the optical fiber. Principle of curvature losses.
2. Theory of coupled modes. Principle of the co- and contra-directional couplers by the perturbative approach. Principle of the Bragg mirror and the external coupler.
3. Photonic components. Illustration of previous chapters by the example study of photonics: Mach Zehnder interferometer, ring filter (all-pass and add-drop), AWG. Introduction to manufacturing methods.

Microwave photonics – Université Rennes 1
Introduction to microwave optics. This module is a first awareness of the specificities of analog optical carrier transmissions compared to optical digital transmissions. The basic tools for modeling such transmissions are presented by showing how the specificities of analog links dictate the choice of opto components used. This module finally aims to address the latest techniques developed for the offset, distribution and all-optical processing of analog signals in the RF and microwave domains.

Module program:

1. Motivation of microwave optics;
2. Merit Factors in Microwave Optics;
3. Specificities and optimization of optoelectronic components for microwave optics;
4. Design and optimization of microwave optical links.

Optical communication technologies (24h, 3 ECTS)

Optical amplification and nonlinear propagation – ENSSAT
The objective of the course, together with the follow-up course “Optical transmission”, is to establish a strong basic culture of optical fiber transmission systems and the physical effects involved in the

propagation of signals in fibers as well as in the amplification mechanisms. Indeed, although demonstrations of transmission capacity beyond 100 Tbit/s in a single optical fiber have been reported, the dispersive and non-linear nature of the transmission medium, as well as its losses, require a good grasp of the physics of propagation and amplification, in order to counteract adverse effects. These effects are studied from a physical (nonlinear propagation, physical mechanisms of amplification) and applicative point of view (taking into account the specificities of the fiber channel in order to define the engineering compromises allowing high speed and long distance transmissions).

Module program:

1. Physics of erbium-doped fiber amplifier
2. Non-linear propagation in optical fibers
3. Third-order elastic non-linear processes: non-linear Schrödinger equation, self-phase modulation, cross-phase modulation, four-wave mixing
4. Inelastic third order nonlinear processes: Raman and Brillouin effects
5. Nonlinear optical fibers and applications to all-optical signal processing.

Optical transmission– ENSSAT

Module program:

1. Elements of transmission systems on optical fibers
2. Linear propagation effect: group-velocity dispersion and modal dispersion
3. Interactions between dispersion and non-linear effects in transmission lines. Different types of optical fibers. Compensation of chromatic dispersion and management of non-linearities
4. Polarization effects
5. Accumulation of noise in amplification chains. Discrete and distributed amplification

Research labworks (2 days/week, 12 ECTS)

This research project is pursue on semester 4.

French as Foreign Language (3 ECTS)

FRENCH as a Foreign language is specifically designed to international students who want to discover the French language and improve their skills in communication. Courses are organized in level groups (A1/ A2 or B1/B2) and are adapted to the students' needs. Innovative teaching materials are used to make the course active and fun. Courses are also meant to make you experience the French culture

Elective courses (up to 4)

Practical work in photonics (24 h, 3 ECTS)

Visit of a fiber platform (PERFOS) and a telecommunication platform (PERSYST).

High speed transmission for access and long distances and special optical fibers –ENSSAT

Optical amplification

Learning objectives

In this assignment, you will learn

1. How to operate and characterize optical amplifiers in terms of amplification bandwidth, gain and gain saturation.

2. How to extract the main features and differences of two types of optical amplifiers, namely erbium-doped fibre amplifiers (EDFAs) and semiconductor optical amplifiers (SOAs).
3. How to select a given type of optical amplifier depending on the application.

Optical transmission and bit-error-ratio measurement

Learning objectives

In this assignment, you will learn

1. How an optical transmission system is implemented from transmitter to transmission line to receiver.
2. How to qualitatively characterize an optical telecommunication signal through eye diagram visualization.
3. How to assess the performance of a digital transmission system thanks to bit-error ratio measurements and determination of the receiver sensitivity and power penalty.
4. How to study the impact of a number of system degradations, including some non-ideal behaviour of the transmitter (extinction ratio limitation) and some impairments induced by the transmission line (group velocity dispersion).

Coherent detection

Learning objectives

In this assignment, you will learn

1. How to implement an optical communication system making use of complex modulation formats, coherent detection and digital signal processing (DSP) at the receiver side.
2. How to use DSP in order to enable a simplified hardware implementation of a coherent receiver and compensate for transmitter and receiver imperfections as well as transmission impairments.
3. How to implement some basic DSP blocks using off-line processing with MATLAB in order to compensate for frequency offset between the transmitter and local oscillator lasers as well as laser phase noise.
4. How to recover a quadrature phase-shift keying (QPSK) signal at 10-Gbaud and evaluate its performance.

Photonic Integrated Circuits Processing

Module contents:

- Clean room environment and technological processing: thin film deposition techniques (spin-coating, sputtering), UV photolithography, dry etching (reactive ion etching (RIE)).
- Photonic integrated circuits (PIC) processing (ridge waveguide fabrication).
- Physical characterizations of thin films and processed components (thickness and refractive index measurements…)
- Optical characterizations at 1.55 µm of processed devices

Learning objectives:

1. Overview of singlemode ridge waveguide design.
2. Understanding of a simple process flow for ridge waveguide fabrication.
3. Understanding of standard techniques for photonic integrated circuits processing.
4. Experimental knowledge of prism coupling for thickness and refractive index measurements.
5. Basic know-how of fiber to PIC optical coupling.

Seminar in Photonics by industrial and academic researchers (24 h/3 ECTS)

The purpose of this series of seminars is to provide overviews of some specific applications of photonics by recognized experts in their fields. About ten seminars are organized each year. The exact content and invited lecturers are different each year. Examples of recently addressed topics are:

- Photonics for agriculture and agronomy
- Photonics in the automobile industry
- Semiconductor lasers on silicon
- Atmospheric LIDARs
- Optical satellite transmission
- Use of photonics and lasers for the conservation and restoration of cultural heritage artwork
- Quantum communications and computing
- Silicon photonics
- Adaptive optics
- High capacity submarine optical transmission systems
- Biomedical optics
- Optical systems for augmented reality
- Etc.

Furthermore, two internal seminars on 1) bibliographical search and 2) scientific writing will be given.

Advanced optical telecommunication systems (12h/2 ECTS)

Optical fiber communication systems have evolved continuously over the past decades, leading to unprecedented throughputs in excess of hundreds of terabits per second. This has been made possible thanks to the introduction of novel technologies, most recently the use of coherent detection associated to digital signal processing. This course will review recent advances in optical communication technologies, beyond the legacy intensity modulation and direct detection systems. It is a natural follow up to the courses “Optical amplification and nonlinear propagation” and “Optical amplification”. It will cover the following points:

- Advanced optical modulation formats and their generation
- Coherent detection and associated digital signal processing
- Space division multiplexing
- Optical communications for short-reach systems, e.g. data centers
- Information theory and optical communications
- Contemporary topics: Kramers-Kronig receivers, nonlinearities mitigation, constellation shaping etc.

Laser noises (16 h /2 ECTS)

This course provides an introduction to noise origins in lasers and their impact on laser characteristics as the relative intensity noise and linewidth. Experimental methods to quantify noises are described and compared. Finally, laser stabilization methods are discussed and applications of narrow linewidth stabilized lasers are presented.

Summer school (24 h / 2 ECTS)

The **ENSSAT international summer school** is a 10 -day- course in the field of *Telecoms and Emerging technologies* at the end of June and beginning of July. The students at Bachelor or Master level will experience specialized training and projects as well as visits of laboratories or telecommunication companies. The school also includes a cultural insight of French culture with French as a foreign language courses and an exciting programme of visits in the beautiful area of the pink Granit coast.