

EUROPHOTONICS EMMC

1st Semester Program

Aix-Marseille III – Université Paul Cezanne – Marseille, France

Fundamentals in Optics and Photonics – 30 ECTS

(1st October – end of March)

Title	EC TS	Hours Lectures	Hours Practice	Location	Contact	e-mail
0. Tutoring TUTORING			30	St Jérôme campus Rouard building	Hugues Giovannini	hugues.giovannini@fresnel.fr
I. Fundamentals in optics FUNDAMENTALS	4	30	30	St Jérôme campus Rouard building	Frédéric Zolla, André Nicolet	frederic.zolla@fresnel.fr, andre.nicolet@fresnel.fr
II. Light radiation and lasers RADIATION	4	40	16	St Jérôme campus Rouard building	Caroline Champenois, Nicolas Sanner	caroline.champenois@univ- provence.fr, sanner@lp3.univ-mrs.fr
III. Fundamentals in optical imaging and microscopy IMAGING	4	32	20	St Jérôme campus Rouard building	Anne Sentenac	anne.sentenac@fresnel.fr
IV. Fundamentals in Biophotonics BIOPHOTONICS	4	44	10	St Jérôme campus Rouard building	Sophie Brasselet, Anabela Da Silva	sophie.brasselet@fresnel.fr, anabela.dasilva@fresnel.fr
V. Fundamentals in Imaging in astronomy ASTRONOMY	4	40	20	LAM (Astronomy Laboratory) Château Gombert Technopôle	Philippe Amram, Brice Le Roux	Philippe.Amram@oamp.fr, brice.leroux@oamp.fr
VI. Lab practice courses LAB	4		60	Ecole Centrale Marseille - Château Gombert Technopôle and St Jérôme campus	Caroline Champenois, Marie Houssin, Laurent Gallais	caroline.champenois@univ- provence.fr, Marie.Houssin@univ- provence.fr, laurent.gallais@fresnel.fr
VII. Personal project and lab work PERSONAL PROJECT	4		100 (personal and tutoring time)	St Jérôme campus	Hugues Giovannini	hugues.giovannini@fresnel.fr
VIII. French language FRENCH	2	40		Ecole Centrale Marseille - Château Gombert Technopôle	Carole Enoch, Virginie Rajaud	carole.enoch@ec-marseille.fr virginie.rajaud@ec-marseille.fr

0. Tutorials

Objectives : *These tutorials are reserved for general discussions/questions with the teachers and/or more developments on a given basic topic.*

There is at least one 2-Hours tutorial per week

Bibliography :

- "Optics", E. Hecht (2001)
- "Geometric, Physical and Visual Optics", M.P. Keating (2002)
- "Introduction to modern optics", G.R. Fowles (1989)
- "Principle of nano-optics", L. Novotny and B. Hecht (2006)
- "Fundamentals of Photonics (Wiley Series in Pure and Applied Optics) ", Bahaa E. A. Saleh, Malvin Carl Teich
- "Les Nanosciences", Marcel Lahmani, Tome 1, Tome 2, Tome 3, ed. Belin - Eyrolles

I. Fundamentals in optics

Objectives : *The general philosophy of these lectures is to explain a large basis of fundamental physical principles indispensable in advanced photonics using the minimum set of mathematical basic concepts necessary for their practical manipulation.*

Prerequisites : *Basics Maths*

1. Mathematical tools : 10h C – 10h TD

- 1.1. Vectors spaces, basis, (multi)linear maps, norms and operators.
- 1.2. Finite dimensional spaces: vectors and matrices.
- 1.3. Infinite dimensional spaces: function spaces and differential operators.
- 1.4. Grad, curl, div, Laplacians and geometry.
- 1.5. Complex analysis.
- 1.6. Distributions, Fourier analysis and Green functions.

2. Classical electromagnetism : 10h C – 10h TD

- 2.1. Maxwell equations *in vacuo*.
- 2.2. Homogenization of simple linear media.
- 2.3. Power, energy and electromagnetic forces.
- 2.4. Wave equations.
- 2.5. Lagrangian and Hamiltonian formulations.

3. Optical approximations : 10h C – 10h TD

- 3.1. Asymptotics: stationary phase.
- 3.2. Fresnel and Fraunhofer diffraction
- 3.3. Paraxial approximation and Gaussian beams.
- 3.4. Geometrical optics.

Tutorials:

Exercises

Contact :

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Participants :

Frédéric Zolla, André Nicolet

Bibliography

- “A Course in Modern Mathematical Physics”, Peter Szekeres, Cambridge University Press 2004.

- “A course in mathematics for students of physics” (tome 1 and tome 2), Paul Bamberg & Shlomo Sternberg, Cambridge University Press 1988.

II. Light radiation and Lasers

Objectives : *The purpose of this course is to present several processes responsible for light emission and to propose a characterization of the emitted light relevant for imaging in terms of coherence and noise. A large part of the lectures is devoted to laser sources, the fundamental concepts they lie on and the properties of light emitted by lasers.*

After an introduction pointing the relevance of coherence for characterizing light sources, the course is split in four parts where coherence is a permanent issue which serves as a guide.

Prerequisites : *the fundamentals introduced in course I are sufficient prerequisites to allow the students to follow this course.*

I. Light emission – 10H C + TD 1 and 2 (A. Sentenac, H. Giovannini)

In this part, we focus on several processes responsible for light emission with some practical examples. These processes can be gathered in three groups concerning

1. *thermal emission,*

This part presents the thermal radiation and its main characteristics as well as recent progress made in the comprehension of such a radiation. We first introduce the thermal radiation in a classical way using the concepts of specific intensity, the Planck function and the Kirchhoff laws. Then, we use the stochastic electrodynamic frameworks to describe more in details the microscopic behaviour of the thermal electromagnetic field. We evaluate the radiation of temperature induced random currents that are generated inside the material. This microscopic approach allows linking the thermal radiation phenomenon to that of luminescence.

2. *luminescence and spontaneous emission,*

The microscopic processes of production of light by individual emitters (atoms and molecules) or semi-conductors (LED) are described. The dynamics and time fluctuations of the emitted light are related to these microscopic processes. It gives the opportunity to introduce the concept of non-classical light by studying emission by single emitters like single atoms or molecules.

3. *stimulated emission,*

This part presents the Einstein theory for matter-light interaction and introduces the fundamental concepts at the origin of light amplification and laser sources.

II. Manipulation and shaping of the emitted light – 8H C + TD 3 and 4 (C. Champenois, M. Houssin)

Keeping in mind coherence as a leading issue, several active processes are introduced which modify the spatial and spectral coherence of the considered sources.

– *spatial filtering,*

Here, selection of the spatial frequencies or propagation wavevectors is presented as a tool to increase coherence properties of source, to the detriment of intensity.

– *frequency filtering,*

As opposition to the previous section, here selection of frequencies and wavevectors is reached through feedback and constructive interferences by an optical cavity.

III. Laser amplifiers and oscillators – 8H C + TD 5 and 6 (M. Houssin, N. Sanner)

1. *Absorption and gain*

Study of the competition between the three main mechanisms (absorption, spontaneous and stimulated emission) lead to understand why the population inversion is a mandatory condition for light amplification.

2. *Relevant spectroscopic systems*

Different spectroscopic systems are described and their respective interests in terms of efficiency, pumping, and population inversion are discussed.

3. *Threshold for laser oscillation in a cavity*

The threshold for laser oscillation is explicitly presented, and we explain why the extracted intensity necessarily reaches a saturation in continuous pumping regime.

Efficiency and output power are also considered.

III. Spectral, spatial and temporal properties of laser emitted light – 14H C + TD 7 and 8 (N. Sanner)

This part is devoted to the specific properties of laser beams.

1. *Cavity stability and beam distribution*

Criteria for resonator stability are presented, in relation with transverse modes. Light emitted by lasers with optical cavity is better described by gaussian modes. Optics with these modes and their focusing properties (obeying rules which can diverge from geometric optics) are introduced.

2. *Beam shaping of gaussian modes*

For imaging applications, gaussian beam are often required to be spatially shaped (e.g. top-hat distribution). Techniques based on spatial phase manipulation are presented.

3. *Pulsed laser sources*

Two different ways to favour stimulated emission are studied: Q-switching (stimulated emission only when there is a large number of atoms in the upper level) and mode-locking (photons in the optical cavity are condensed into a “packet” or “pulse” that will bounce back and forth between the mirrors). The case of ultrashort pulses is also studied, and frequency combs are introduced as the achievement of frequency control of a pulsed laser which allows precise comparison and measurement of optical frequencies.

4. *Frequency multiplication and nonlinear optical effects*

Laser frequencies that are not directly available with a laser medium can be generated by using non-linear effects (that are permitted owing to the high intensity of laser beams). A brief introduction to NL optics in dielectric materials will precede a detailed presentation of several common NL processes (2nd and 3rd order mainly) that serves in numerous imaging techniques.

5. *Review of up-to-date commercial sources and their applications*

Different types of lasers (with gaseous, solid or semi-conductor amplifying media) with their principles of operation are reviewed, accompanied by their common applications, from telecommunications to biophotonics and imaging.

6. *Fluctuations and noise*

We introduce frequency and intensity fluctuations in laser source. The noise associated with intensity measurement is also explained.

Tutorials: (16H)

- 1- Emission from a lamp.
- 2- Einstein coefficients, stimulated vs spontaneous emission for different spectral range.
- 3- Spatial filtering
- 4- Frequency filtering with a cavity
- 5- Study of a Nd:YAG laser – part 1
- 6- Study of a Nd:YAG laser – part 2
- 7- Pulsed lasers
- 8- Second harmonic generation

Coordinators :

Caroline Champenois, PIIM, CNRS, caroline.champenois@univ-provence.fr

Nicolas Sanner, LP3, Université de la Méditerranée, sanner@lp3.univ-mrs.fr

Participants :

Caroline Champenois, Hugues Giovannini, Marie Houssin, Nicolas Sanner, Anne Sentenac,
Frank Wagner

Bibliography

"Laser fundamentals", W. Silfvast, Cambridge University Press

"Lasers", A.E. Siegman, Science Books

"Quantum electronics" Yariv, Wiley

"Elements of quantum optics", P Meystre and M. Sargent III, Springer Verlag

III. Fundamentals in optical imaging and microscopy

Objectives : *Introduce a rigorous formalism for the image formation in a microscope in order to be able to account for all aspects such as resolution etc – Construct an optical propagation through a complex set-up.*

Prerequisites : *Basic maths*

I. Propagation of the field – 4H C

We analyse the way the field propagates far from its source. We use the Green formalism to investigate the properties of the field in near-field or in far-field. Emission of a dipole (vectorial description) – Evanescent and radiative contributions. Loss of information due to propagation. Vectorial nature of the radiated field.

II. Analysis of the resolution of an imaging system – 8H C

1. Active imaging systems : we consider a formal imaging system in which the object is illuminated by a plane wave and its diffracted field is recorded in far-field. We show the link between the diffracted field and the spatial fourier components of the object contrast. We introduce the concepts of Ewald Sphere, Numerical Aperture and Point Spread Function.
2. Passive systems imaging

III. Analysis of simple imaging systems – 6H C

1. Three simple microscopes : as a direct application of the previous courses, we study the image formation in a wide-field microscope, a fluorescence microscope and a confocal microscope in an electromagnetic framework. We specify the notion of point spread function in these particular cases.
2. Telescopes

IV. Components for imaging - 14H C (*M. Lequime*)

The main objective of this course is to define and illustrate the basic concepts driving the design and working of an optical imaging system.

Photometry

- Optical throughput (definition, conservation rule, consequences)
- Radiometry and Visual photometry (definitions, units)
- Apertures, stops, numerical aperture, field of view
- Telecentric systems

Optical filters

- Fundamentals of optical interference coatings
- Main filtering functions (objectives, specifications)
- Filter implementation: practical rules

Scanning devices

- Opto-mechanical systems (galvanometers, rotating mirrors)
- MOEMS (Digital Micro Mirrors)

Optical design software

- Ray tracing software (OSLO)
- Thin-film software (TFCalc)

Tutorials: 20H TD (*P. Ferrand, M. Lequime*)

Basics in imaging
Optical Design Software (optical thin films)

Coordinators :

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P. Ferrand, Institut Fresnel, Université Aix Marseille III, patrick.ferrand@fresnel.fr

Participants :

Anne Sentenac, Guillaume Maire, Hugues Giovannini, Patrick Ferrand, M. Lequime

IV. Fundamentals in Biophotonics

Objectives : Give an overview of the observed systems in biophotonics, on the biological side (introduction to biology) as well as on the photonics side (optical contrasts, optics in tissues). Presentation of the challenges linked to medical imaging in the case of biological tissues. Presentation of tissues morphology and their optical properties, for different tissues types.

Prerequisites : Basic optics and matter sciences

I. Optical contrasts in biological imaging : 14H C (*S. Brasselet*)

Molecular contrasts : refraction index, absorption, elastic scattering (elastic oscillation of electrons, classical and quantum aspects)

Electronic and vibrational transitions

Radiative emission: fluorescence (absorption and emission probabilities), inelastic scattering (Raman, Brillouin)

Multiphotonic processes : harmonic generation (nonlinear susceptibilities)

Symmetry and molecular spectral signatures

Coherent and incoherent emission processes: specificities and applications

Polarization sensitivity and fluorescence anisotropy

Applications for bio-imaging : molecular probes and intrinsic contrasts in cells and tissues

II. Introduction to biology : 16H C (*C. Favard, PF Lenne*)

A brief introduction to Biology :

- 1- Elementary components of Biology: Molecules, macromolecules, their synthesis and properties. (2h, *C. Favard*)
- 2- Assembling macromolecules within cells : Biological polymers and their role in the cell (2h, *C. Favard*)
- 3- The cell: Cellular compartmentalization, cellular organelles, assembling cells in tissues. (2h, *C. Favard*)
- 4- The membrane : self-assembly, diffusion and organization (2h, *PF Lenne*)
- 5- The cytoskeleton : cellular forces and shapes (2h, *PF Lenne*)
- 6- Cell movements (2h, *PF Lenne*)
- 7- Morphogenesis of cells and tissues (2h, *PF Lenne*)

III. Tissue Optics : 14 H C (*A. Da Silva, C. Deumié, M. Commandré*)

Light interaction with biological tissues is governed by two concurrent light-matter interaction processes: absorption and scattering.

1- Absorption in tissues

Presentation of biological chromophores (molecules that absorb light) and their action in absorption in biological tissues.

Electronic and vibrational transitions. Definition and units of absorption coefficient μ_a [cm^{-1}] and examples of absorption spectra for biological tissues.

2- Fluorescence in tissues

Fluorescence of biological tissues - Biological tissue labels

3- Scattering in tissues

- Main biological scatterers.
- Definition and units of the physical parameters defining the scattering phenomenon (scattering coefficient μ_s [cm⁻¹], anisotropy factor g , Scattering functions, Isotropic scattering function, Henyey-Greenstein scattering function), Reduced scattering coefficient $\mu_s' = \mu_s(1 - g)$ [cm⁻¹]
- Examples of scattering patterns from biological ultra structures (cellular structure of soft tissues; collagen fibers of dermis...)

4- Diagnostic and Imaging through biological tissues

The case of low scattering levels: Optical Coherence Tomography and imaging

The case of high scattering levels: inverse problem in simple cases and brief overview of different optical techniques for screening different kinds of biological tissues.

Tutorials: 10H

1. Single molecule fluorescence emission: efficiency, polarization dependence, detection in a microscope
2. Coherence of radiation from an emitter
3. Inelastic oscillation of electrons and nonlinear radiation
- 4 & 5. Calculating and measuring absorption and scattering
Example calculation of angular scattering pattern; Example calculation of anisotropy;
Example calculation of scattering cross section and coefficient; Scattering versus wavelength for different particle sizes in computer lab.

Coordinators :

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Participants :

Anabela Da Silva, Sophie Brasselet, Cyril Favard, PF Lenne, M. Commandré, C Deumié

Bibliography :

- "Principles of Fluorescence Spectroscopy", Joseph R. Lakowicz Kluwer Academic Publishers
- "Introduction to Biophotonics", Paras N. Prasad
- "Handbook of biomedical nonlinear optical microscopy", Barry R. Masters, Peter T. C. So

-...

V. Fundamentals of Imaging in astronomy

Objectives : *Handling real problems in astronomical data analysis through a modern arsenal of powerful techniques and instruments. Effective, relevant and innovative methods of image, signal, spectra and data processing are developed:*

Prerequisites : *Basic optics*

Astronomical optics: 10H C (*P.Amram, O.Lefevre + 1 seminar*)

a first global and unified approach
échantillonnage/champs/... vs objectifs astro.

Imagery/imaging: 10H C (*L.Jorda & J.-G. Cuby +1 seminar*)

radiométrie , calibration géométrique et photométrie, detection and filtering,
DéTECTEURS/calibrations/utilisation
(*deconvolution, multichannel, multiscale, wavelets transforms, pattern recognition, synthetic*)

Spectro-imagery/imaging: 10H C (*J.-G. Cuby, F. Zamkotsian, K. Dohlen +1 seminar*)

dispersive technics (GRISM, holographic gratings)
interferential technics (Fabry-Perot, Michelson, Fourier Transform)
new components in micro-optics (MOEMS, slicers, ...)
and theirs applications in astronomical instrumentation.

Adaptive Optics I: 10H C (*B. LeRoux, J.-M. Conan(Onera) +1 seminar*)

Analysis, systems (presentation of AO system, its component and limitations)

Tutorials: 20H

To be completed

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Participants :

P. Amram, O. Lefevre, L. Jorda, J.-G. Cuby , F. Zamkotsian, K. Dohlen, B. LeRoux, J.-M. Conan (Onera)

Bibliography :

- Kitchin, “Astrophysical Technics”, 5th édition, CRC Press
- Léna Pierre , “Observational Astrophysics”, Springer-Verlag
- Roddier, “Adaptive Optics in Astronomy”, Cambridge University Press
- “Spectrophysics: Principles and Applications” Anne Thorne, Ulf Litzén, Sveneric Johansson, Ulf Litzen

VI. Lab practice courses

Objectives : *give to the students a strong practical knowledge of optical components and concepts. One of the purpose is to make them familiar with all the basic tools contained by most experiments and devices using optics, so they are able to propose solutions in very different situations.*

Prerequisites : *Lectures of this semester*

I. “Fundamentals” practice courses : 40H (10 courses)

1. Nd:YAG-laser (cw, Q-switch, frequency doubling)
2. diffraction, spatial filtering in the Fourier plane
3. making a good picture: how it works with a camera
4. interferometry (Michelson)
5. holography
6. optical telecommunications by fibers
7. image construction and projection
8. polarisation of light and polarisation sensitive optical components
9. microscopy
10. spectroscopy

II. “Lab” practice courses : 20H (5 courses)

The students can choose 5 among all these proposed subjects:

- 1- Confocal microscopy and resolution measurements : Patrick Ferrand
- 2- Introduction to nonlinear microscopy : Sophie Brasselet
- 3- Single molecule fluorescence microscopy : Jérôme Wenger
- 4- Polarisation resolved microscopy : Sophie Brasselet
- 5- Fullwave tutorial: electromagnetic simulations : Jérôme Wenger
- 6- Labview tutorial: lab interfacing : Patrick Ferrand
- 7- Laser Induced Breakdown Spectroscopy (MAP2 Fresnel-Laurent Gallais)
- 8- Speckle Interferometry (MAP2 Fresnel-Gaëlle Georges)
- 9- laser material processing (MAP2 Fresnel-Laurent Gallais)
- 10- Microscopy for biomedical applications (MAP2 Fresnel-Gaëlle Georges)
- 11- Emission spectroscopy of a magnetized plasma : Alexandre Escarguel
- 12- Ultrafast laser ablation : Nicolas Sanner
- 13- Spectral analysis of a continuous wave laser : Caroline Champenois
- 14- Study of an optical cavity (eigen modes, mode-matching) : Caroline Champenois
- 15- Micro-Raman spectroscopy: a characterisation of samples extracted from Tokamaks : C. Pardanaud
- 16- Ultrafast laser ablation (N. Sanner)
- 17- Pump-probe (N. Sanner)
- 18- Laser cleaning (N. Sanner)
- 19- Laser nanostructuring (N. Sanner)
- 20- Laser printing (N. Sanner)

Coordinators :

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Participants for the fundamental courses:

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Frédéric Lemarquis, Jérôme Wenger

VII. Projects

Objectives : *preparing the students to a bibliography work on a research topic and illustrating it with practical examples of experiments and/or theoretical developments : 100 H in total for 1 semester personal work starting in November.*

Prerequisites : *Lectures from this semester*

TOPICS :

Institut Fresnel

MOSAIC

- Nonlinear microscopy for bio-imaging in tissues
- Polarization-resolved microscopy
- Laser optical feedback tomography
- Microscopy with an isotropic resolution : "4- π microscopy" and "incoherent interference illumination and image interference microscopy (ISM)"
- Adaptative optics in microscopy

RCMO

- Phase properties of optical interference coatings
- Spectral properties of planar multilayer micocavities

LP3

- Ultrashort laser interaction with solids
- Ultrafast pump-probe techniques

CLARTE

- Particle swarm optimization

MAP2

- Study of a polarimetric imaging system for biomedical applications

SEMO

- Optical tomography

LAM

- Adaptative optics
- spectro-imaging
- dynamics imaging in astronomy

PIIM

- How to measure an optical frequency
- How to control a laser frequency

To be completed

Contact :

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VIII. French language and culture

Objectives : *Variable, depending on students' familiarity with target language.*

Elementary Level Objectives (Level A1 of European framework)

- **Language:** Increased familiarity with authentic language use in various communicational contexts. Understanding contextual cues (announcements, signs, etc.). Ability to introduce oneself, ask simple questions, and speak about everyday subjects with the help of other speakers.
- **Culture:** Basic knowledge of French culture (art, cooking, history, etc.) as well as certain regional and local characteristics. Ability to recognize typical patterns and behavior in formal and informal interaction.

Prerequisites: None

Threshold Level Objectives (Level B1 – B2 of European framework)

- **Language:** Understanding the key points of a message delivered in clear, standard language. Ability to converse about familiar subjects or current events. Ability to speak about one's opinions, experiences and goals. Ability to write a simple, coherent message.
- **Culture:** Deepening knowledge of French culture (art, cooking, history, etc.) as well as regional and local characteristics. Ability to recognize and use context-specific patterns of formal and informal interaction.

Prerequisites: B1 level

On-campus courses will be held in ordinary classrooms as well as multimedia labs. Certain courses will take place off-campus, in museums and other cultural venues in and around Marseille. Courses are between 2 and 3 hours long.

Coordinator : Virginie Rajaud (ECM)

Instructors : Virginie Rajaud (ECM), Gerald Marquis (ECM)