



POLITÉCNICA

INTERNATIONAL  
CAMPUS OF  
EXCELLENCE

COORDINATION PROCESS OF  
LEARNING ACTIVITIES  
PR/CL/001



E.T.S. de Ingenieros de  
Telecomunicacion

# ANX-PR/CL/001-01

## LEARNING GUIDE

### SUBJECT

**93000929 - Computational Electromagnetics**

### DEGREE PROGRAMME

09AT - Master Universitario En Teoria De La Señal Y Comunicaciones

### ACADEMIC YEAR & SEMESTER

2025/26 - Semester 2

## Index

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### Learning guide

1. Description.....	1
2. Faculty.....	1
3. Prior knowledge recommended to take the subject.....	2
4. Skills and learning outcomes .....	2
5. Brief description of the subject and syllabus.....	4
6. Schedule.....	8
7. Activities and assessment criteria.....	12
8. Teaching resources.....	15

## 1. Description

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### 1.1. Subject details

<b>Name of the subject</b>	93000929 - Computational Electromagnetics
<b>No of credits</b>	6 ECTS
<b>Type</b>	Optional/elective
<b>Academic year of the programme</b>	First year
<b>Semester of tuition</b>	Semester 2
<b>Tuition period</b>	February-June
<b>Tuition languages</b>	English
<b>Degree programme</b>	09AT - Master Universitario en Teoría de la Señal y Comunicaciones
<b>Centre</b>	09 - E.T.S. De Ingenieros De Telecomunicacion
<b>Academic year</b>	2025-26

## 2. Faculty

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### 2.1. Faculty members with subject teaching role

<b>Name and surname</b>	<b>Office/Room</b>	<b>Email</b>	<b>Tutoring hours *</b>
Jorge Alfonso Ruiz Cruz	B-411	jorge.ruizcruz@upm.es	Sin horario. Appointment arranged by email
Juan Corcoles Ortega (Subject coordinator)	B-415	juan.corcoles@upm.es	Sin horario. Appointment arranged by email

\* The tutoring schedule is indicative and subject to possible changes. Please check tutoring times with the faculty member in charge.

## 3. Prior knowledge recommended to take the subject

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### 3.1. Recommended (passed) subjects

The subject - recommended (passed), are not defined.

### 3.2. Other recommended learning outcomes

- Electromagnetic fields theory. (Teoría de campos electromagnéticos)
- Microwave engineering. (Ingeniería de microondas)
- Discrete numerical analysis (Análisis numérico discreto)
- Linear Algebra (Álgebra lineal)

## 4. Skills and learning outcomes \*

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### 4.1. Skills to be learned

CB06 - Poseer y comprender conocimientos que aporten una base u oportunidad de ser originales en el desarrollo y/o aplicación de ideas, a menudo en un contexto de investigación

CB07 - Que los estudiantes sepan aplicar los conocimientos adquiridos y su capacidad de resolución de problemas en entornos nuevos o poco conocidos dentro de contextos más amplios (o multidisciplinares) relacionados con su área de estudio

CB08 - Que los estudiantes sean capaces de integrar conocimientos y enfrentarse a la complejidad de formular juicios a partir de una información que, siendo incompleta o limitada, incluya reflexiones sobre las responsabilidades sociales y éticas vinculadas a la aplicación de sus conocimientos y juicios

CB09 - Que los estudiantes sepan comunicar sus conclusiones y los conocimientos y razones últimas que las sustentan a públicos especializados y no especializados de un modo claro y sin ambigüedades

CB10 - Que los estudiantes posean las habilidades de aprendizaje que les permitan continuar estudiando de un modo que habrá de ser en gran medida autodirigido o autónomo

CE01 - Analizar y aplicar técnicas para el diseño y desarrollo avanzado de equipos y sistemas, basándose en la teoría de la señal y las comunicaciones, en un entorno internacional

CE02 - Evaluar y sintetizar los resultados de un trabajo en equipo en proyectos relacionados con la teoría de la señal y las comunicaciones, en un entorno internacional.

CE03 - Valorar y contrastar la utilización de las diferentes técnicas disponibles para la resolución de problemas reales dentro del área de teoría de la señal y comunicaciones.

CT01 - Capacidad para comprender los contenidos de clases magistrales, conferencias y seminarios en lengua inglesa

CT03 - Capacidad para adoptar soluciones creativas que satisfagan adecuadamente las diferentes necesidades planteadas

CT04 - Capacidad para trabajar de forma efectiva como individuo, organizando y planificando su propio trabajo, de forma independiente o como miembro de un equipo

CT05 - Capacidad para gestionar la información, identificando las fuentes necesarias, los principales tipos de documentos técnicos y científicos, de una manera adecuada y eficiente

CT06 - Capacidad para emitir juicios sobre implicaciones económicas, administrativas, sociales, éticas y medioambientales ligadas a la aplicación de sus conocimientos

## 4.2. Learning outcomes

RA37 - The capacity to choose the most suitable methods and tools for each problem electromagnetic problem and use it solve the given problem

RA35 - Understanding the need of computational electromagnetics

\* The Learning Guides should reflect the Skills and Learning Outcomes in the same way as indicated in the Degree Verification Memory. For this reason, they have not been translated into English and appear in Spanish.

## 5. Brief description of the subject and syllabus

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### 5.1. Brief description of the subject

#### Course Description

This course presents most of the commonly computational techniques used to solve electromagnetic problems in microwave engineering. These techniques are commonly used to a precise characterization of structures involved in the design and development of devices and antennas. These methods are presented to know their features, advantages and limitations and how or where can be used, as well as their performances against the others.

#### Course Goal

To reach the understanding of the need of computational electromagnetic in the design of advanced microwave devices, the features of the most common used methods, the ability of developing basic own codes for these designs and using properly the available tools.

#### Summary of intended course outcomes

At the conclusion of the course, students should be able to understand the concepts and models used in Computational Electromagnetics and also will be able to apply these to advanced engineering problems, choosing the most suitable method for them, and having the capacity of using the available commercial tools or even developing their own basic methods when required

By the end of the course the students will reach the abilities of:

1. Understanding the need of computational electromagnetics.
2. Knowing the most common computational techniques and methods used to analyse the microwave circuits and antennas.
3. Knowing the basis of these methods and, as consequence, the advantages and drawbacks of each of them.
4. As results of the previous, they will have the capacity to choose the most suitable methods and tools for each problem.

5. Knowing some of the commercial available tools based of these method, the capacity of choosing the most convenient tool and the basic knowledge of their use.

## Course methodology

The course methodology will follow a *learning-by-doing* approach and, as such, the schedule of the course will not simply correspond to the timing of the syllabus. The different items in the syllabus will be learned by students through a combination of master classes and laboratory classes.

## 5.2. Syllabus

### 1. Fundamentals of electromagnetics

#### 1.1. Overview of electromagnetic regimes/solvers

##### 1.1.1. Static and quasi-static

##### 1.1.2. Full-wave

##### 1.1.3. Asymptotic

##### 1.1.4. Multiphysics

#### 1.2. Formulations

##### 1.2.1. Time Domain vs Frequency Domain

##### 1.2.2. Differential Equation vs Integral Equation

#### 1.3. Materials

##### 1.3.1. Dielectrics

##### 1.3.2. Conductors

#### 1.4. Boundary conditions

##### 1.4.1. Perfect Electric/Magnetic conductors

##### 1.4.2. Surface Impedance Boundary Conditions

##### 1.4.3. Radiation/Absorbing Boundary Conditions and Perfectly Matched Layers

##### 1.4.4. Periodic Boundary Conditions

##### 1.4.5. Symmetries

- 1.4.6. Imposing excitations
2. Fundamentals of computational methods
  - 2.1. Discretization and basis functions
    - 2.1.1. The concept of discretization: adapting formulations to numerical methods
    - 2.1.2. The concept of basis functions: degrees of freedom in a numerical method
    - 2.1.3. Entire-domain vs subsectional basis functions
    - 2.1.4. Structured vs unstructured meshes
  - 2.2. Basics of numerical analysis
    - 2.2.1. Accuracy: round-off errors and floating-point arithmetic
    - 2.2.2. Convergence: absolute and relative
    - 2.2.3. Stability: implicit vs explicit time-domain schemes
    - 2.2.4. Derivative approximations and numerical quadratures
  - 2.3. Matrices and linear systems
    - 2.3.1. Dense vs banded vs sparse matrices
    - 2.3.2. Direct vs iterative solvers
    - 2.3.3. Eigenproblems
    - 2.3.4. Root-finding algorithms
3. Fundamentals of computing platforms in relation with computational electromagnetics
  - 3.1. Hardware: RAM and other cache memories, CPU vs GPU
  - 3.2. Parallelization: threads, processors, shared/distributed memory, acceleration and nodes
4. Combining computational electromagnetics with optimization for full-wave design
  - 4.1. Types of optimization: deterministic vs heuristic, local vs global
  - 4.2. Cost function and constraints on parameters
5. Finite Element Method (FEM)
  - 5.1. Fundamentals of FEM
  - 5.2. Overview of free and commercial FEM solvers: Ansys HFSS, CST Frequency Domain/Eigenmode Solver, The FEniCS computing platform
6. Integral Equation (IE) and Method of Moments (MoM)
  - 6.1. Fundamentals of IE and MoM

- 6.2. Overview of free and commercial IE and MoM solvers: CST Integral Equation Solver, Keysight ADS Momentum, Altair FEKO, 4nec2
- 7. Finite-difference time-domain (FDTD) and Finite-integration technique (FIT)
  - 7.1. Fundamentals of FDTD and FIT
  - 7.2. Overview of free and commercial time-domain solvers: CST Time Domain Solver, SEMCAD X
- 8. Other CEM methods exploiting knowlegde of the problem
  - 8.1. Quasi-analytical methods: the mode-matching case. Overview of solvers: Mician
  - 8.2. Asymptotic methods: Geometrical Optics (GO), Physical Optics (PO) and the Geometrical and Uniform Theory of Diffraction (GTD/UTD). Overview of solvers: CST Asymptotic Solver, TICRA GRASP

## 6. Schedule

### 6.1. Subject schedule\*

Week	Type 1 activities	Type 2 activities	Distant / On-line	Assessment activities
1	<p>The need of electromagnetic modeling. Purpose and scope of application. Why do we need computational electromagnetics? Duration: 02:00 Lecture</p> <p>Study case: connection of two transmission lines. The circuital vs the electromagnetic approach. Duration: 02:00 Lecture</p>			
2	<p>Connection of two transmission lines: analyzing the coaxial case Duration: 02:00 Laboratory assignments</p> <p>Connection of two transmission lines: the microstrip case Duration: 02:00 Laboratory assignments</p>			
3	<p>Basics of Computational Electromagnetics explained through the Finite Element Method (FEM) in the Frequency Domain Duration: 02:00 Lecture</p> <p>Fundamentals of the Finite Element Method: What are the unknowns of our problem? What kind of mesh do we need? How are the matrices of the linear system approximating Maxwell's equations? Duration: 02:00 Lecture</p>			
4	<p>Simulating closed metallic cavities with inner dielectrics using free and/or commercial FEM solvers Duration: 02:00 Laboratory assignments</p> <p>Simulating a waveguide coupler and other devices using free and/or commercial FEM solvers Duration: 02:00 Laboratory assignments</p>			

5	<p><b>FEM for open problems: is it a natural approach? The use of special boundary conditions. Are there better suited approaches?</b> Duration: 02:00 Lecture</p> <p><b>Integral Equation (IE) and the Method of Moments (MoM): a natural approach for open problems</b> Duration: 02:00 Lecture</p>			
6	<p><b>Fundamentals of IE and MoM: What are the unknowns of our problem? What kind of mesh do we need? How are the matrices of the linear system approximating Maxwell's equations?</b> Duration: 02:00 Lecture</p> <p><b>Simulating wire and metallic antennas using free and/or commercial MoM solvers. Comparison with FEM solutions.</b> Duration: 02:00 Laboratory assignments</p>			
7	<p><b>Simulating the Radar Cross Section (RCS) of metallic objects using free and/or commercial MoM solvers. Comparison with FEM solutions.</b> Duration: 02:00 Laboratory assignments</p> <p><b>Simulating microstrip circuits and antennas using free and/or commercial MoM solvers. Comparison with FEM solutions.</b> Duration: 02:00 Laboratory assignments</p>			
8	<p><b>Changing to the time domain and its implications. The Finite-Difference Time-Domain (FDTD) and Finite-Integration Technique (FIT)</b> Duration: 02:00 Lecture</p> <p><b>Fundamentals of FDTD and FIT: What are the unknowns of our problem? What kind of mesh do we need? Why the time step is critical for numerical stability?</b> Duration: 02:00 Lecture</p>			
9	<p><b>Simulating a waveguide filter using free and/or commercial time-domain solvers .Comparison of time-domain vs frequency-domain approaches for resonant vs. non-resonant problems.</b> Duration: 02:00 Laboratory assignments</p> <p><b>Simulating a microstrip antenna using free and/or commercial time-domain solvers .Comparison of time-domain vs</b></p>			

	<p>frequency-domain approaches for resonant vs. non-resonant problems. Duration: 02:00 Laboratory assignments</p>			
10	<p>Exploiting advanced electromagnetic knowledge of the problem: the way towards quasi-analytical methods. A quasi-analytical technique for waveguide problems: mode-matching Duration: 02:00 Lecture</p> <p>Asymptotic methods exploiting prior knowledge in open problems: Geometrical Optics (GO); Physical Optics (PO) and the Geometrical and Uniform Theory of Diffraction (GTD/UTD) Duration: 02:00 Lecture</p>			
11	<p>Simulating waveguide devices using free and/or commercial mode-matching solvers. Comparison with general-purpose full-wave solvers Duration: 02:00 Laboratory assignments</p> <p>Simulating antennas and RCS using free and/or commercial asymptotic solvers. Comparison with general-purpose full-wave solvers Duration: 02:00 Laboratory assignments</p>			
12	<p>Wrapping up a unified vision of Computational Electromagnetics (CEM): electromagnetic regimes/solvers and formulations, materials, boundary conditions, discretization and basis functions Duration: 02:00 Lecture</p> <p>Wrapping up a unified vision of CEM: numerical analysis, matrices and linear systems, parallelization and CPUs vs GPUs Duration: 02:00 Lecture</p>			
13	<p>Combining CEM with optimization techniques in radiofrequency: fundamentals Duration: 02:00 Lecture</p> <p>Combining CEM with optimization techniques in radiofrequency: applications Duration: 02:00 Laboratory assignments</p>			

14	<p><b>Analysis and design work assignment.</b> <b>Presentation of the performed work and the obtained results.</b> Duration: 04:00 Additional activities</p>			<p><b>Analysis and design work assignment.</b> <b>Presentation of the performed work and the obtained results.</b> Group presentation Progressive assessment Presential Duration: 00:00</p>
15				
16				<p><b>Final exam. (Progressive assessment)</b> Written test Progressive assessment Presential Duration: 03:00</p>
17				<p><b>Final exam. (Global assesment)</b> Written test Global examination Presential Duration: 03:00</p> <p><b>Analysis and design work assignment .</b> <b>Presentation of the performed work and the obtained results.</b> Individual presentation Global examination Presential Duration: 02:00</p>

Depending on the programme study plan, total values will be calculated according to the ECTS credit unit as 26/27 hours of student face-to-face contact and independent study time.

## 7. Activities and assessment criteria

### 7.1. Assessment activities

#### 7.1.1. Assessment

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
14	Analysis and design work assignment. Presentation of the performed work and the obtained results.	Group presentation	Face-to-face	00:00	50%	2 / 10	CB08 CB09 CT01 CB07 CT03 CB06 CE02 CT04 CE01 CT06 CE03 CT05 CB10
16	Final exam. (Progressive assessment)	Written test	Face-to-face	03:00	50%	2 / 10	CB08 CB09 CT01 CB07 CT03 CB06 CE02 CT04 CE01 CT06 CE03 CT05 CB10

#### 7.1.2. Global examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
17	Final exam. (Global assesment)	Written test	Face-to-face	03:00	50%	2 / 10	CB08 CB09 CT01 CB07 CT03 CB06 CE02 CT04 CE01

							CT06 CE03 CT05 CB10
17	Analysis and design work assignment . Presentation of the performed work and the obtained results.	Individual presentation	Face-to-face	02:00	50%	2 / 10	CB08 CB09 CT01 CB07 CT03 CB06 CE02 CT04 CE01 CT06 CE03 CT05 CB10

### 7.1.3. Referred (re-sit) examination

Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
Final Exam. (Global assessment)	Written test	Face-to-face	03:00	50%	2 / 10	CB08 CB09 CT01 CB07 CT03 CB06 CE02 CT04 CE01 CT06 CE03 CT05 CB10

Analysis and design work assignment . Presentation of the performed work and the obtained results.	Individual presentation	Face-to-face	02:00	50%	2 / 10	CB08 CB09 CT01 CB07 CT03 CB06 CE02 CT04 CE01 CT06 CE03 CT05 CB10
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## 7.2. Assessment criteria

Students will be qualified by default through the same procedure: progressive evaluation, composed by the 50% of student workshops (homework), which will be explained in a presentation, and by 50% of an exam covering the most important topics of the subject. To be accepted to the progressive evaluation the students must to attend at least to the 75% of the lectures. Students who do not meet this requirement will be qualified according to global evaluation .

Evaluation will assess if students have acquired all the competences of the subject. Thus, any evaluation will be carried out considering all the evaluation techniques used usually in progressive evaluation (EX, ET,TG, etc.).

The evaluation of those students on non-progressive assessment (global evaluation) will be composed by the 50% of student workshops (homework), which will be explained in a presentation, and by 50% of an exam covering the most important topics.

The evaluation on referred (re-sit) examination will be composed by the 50% of student workshops (homework), which will be explained in a presentation, and by 50% of an exam covering the most important topics.

## 8. Teaching resources

### 8.1. Teaching resources for the subject

Name	Type	Notes
Support Web Page	Web resource	A support web page will be available to provide relevant additional information to students.
David. B Davidson, "Computational Electromagnetics for RF and Microwave Engineering", Cambridge University Press, 2005.	Bibliography	Generic reference. It covers FDTD and MoM and FEM
Allen Taflove, "Computational Electrodynamics: The Finite-Difference Time-Domain Method", Artech House, 2005.	Bibliography	Reference for FDTD.
Roger F. Harrington, "Field Computation by Moment Methods", I.E.E.E.Press, 1993	Bibliography	Reference for the Method of Moments.
Rebollar, Page de la Vega, Encinar, Camacho, Esteban, "Temas Avanzados en teoría electromagnética", Servicio de Publicaciones ETSI de Telecomunicación, 1992.	Bibliography	For Mode Matching.
Jianming Jin, "The Finite Element Method in Electromagnetics", John Wiley & Sons, Inc. 2002	Bibliography	It covers finite elements.
McNamara, Pistorius, Malherbe, "Introduction to the Uniform Geometrical Theory of Diffraction", Artech House, 1990.	Bibliography	It covers GO, PO, GTD, UTD.

Pyotr Ya. Ufimtsev, "Fundamentals of the Physical Theory of Diffraction". John Wiley & Sons	Bibliography	It covers GTD-UTD
Walton C. Gibson - The Method of Moments in Electromagnetics, CRC Press , 28 nov. 2007 - 288 páginas	Bibliography	Reference for the Method of Moments
C. Balanis. "Advanced Engineering Electromagnetics". John Wiley & Sons. 1989	Bibliography	Reference for GTD, UTD and PO