UNICUSANO ROME

**Italian code: ING-INF/02 (old) – IINF-02/A (new)** **Credits: 6**
**Course: Electromagnetic Artificial Materials**
**Main language of instruction:** Italian
**Other language of instruction:** English

## Head instructor

**Professor Michela LONGHI - michela.longhi@unicusano.it**

## Objectives

The course is designed to provide the methodologies and skills needed for the characterization of artificial electromagnetic materials and surfaces.
In particular, the course provides theoretical and practical information on the main characteristics of these innovative materials.
This course places us in the field of electromagnetic fields and broadens and deepens the knowledge acquired in the courses of Electromagnetic Fields and Guided Propagation and Microwave Circuits, introducing new theoretical and applicative topics on artificial electromagnetic materials.

## Course structure

- Module 1 – Electromagnetic Field Reminders
- Module 2 – Interaction between electromagnetic field and natural materials
- Module 3 – Interaction between electromagnetic field and artificial materials
- Module 4 – Introduction to Metamaterials and Metasurfaces
- Module 5 – Electromagnetic invisibility, imaging and sensing
- Module 6 – Electromagnetic Simulation Software (CST)

## Competencies

A. Knowledge and understanding:

At the end of the course, the student will know the terminology, properties and characteristics of advanced electromagnetism applied to artificial electromagnetic systems. He will also master the mechanisms of interaction between electromagnetic field and natural/artificial materials and the physical quantities used to describe it.

B. Applying knowledge and understanding:

In order to address issues related to aspects of electromagnetism applied to artificial surfaces and materials, even in contexts of considerable complexity, through the application of knowledge, the student must be able to correctly interpret problems of analysis and design of these materials. At the end of the course, the student will have developed analysis and characterization skills necessary to be able to choose and apply techniques and design tools to synthesize artificial electromagnetic materials and surfaces and will be able to recognize their main applications in different scientific and technological fields.

C. Making judgements:

At the end of the course, the student will have acquired the ability to choose and design a suitable artificial electromagnetic material or surface for a specific application that satisfies certain design specifications. Furthermore, the student will have developed a critical ability to interpret the results obtained during the performance of a numerical exercise and a simulation both in terms of physical coherence of the results obtained and in terms of engineering feasibility of the solution identified.

D. Communication skills:

At the end of the course, the student will have developed a correct and comprehensible scientific language that will allow him to express in a clear and unambiguous way the technical knowledge acquired in the field of the theory of artificial electromagnetic materials and antennas.

E. Learning skills:

At the end of the course, the student will have developed the ability to apply the knowledge acquired to solve unfamiliar problems that have as their object the design of artificial electromagnetic materials or surfaces.

**<u>Syllabus</u>**

**Module 1 – Electromagnetic Field Reminders**

Maxwell's equations and boundary conditions.
Complex notation and polarization.
Fundamental theorems.
Vector potentials.
Green's function in free space.
Hertz dipole.
Radiation.
Uniform/non-uniform electromagnetic waves.

Phase and group velocities.
Constitutive relations and classification of materials (bi-anisotropic, anisotropic, bi-isotropic, isotropic): linear/non-linear, homogeneous/non-homogeneous, stationary/non-stationary, local/non-local, dispersive/non-dispersive materials.
Constitutive parameters in the frequency and wavenumber domain. Ù
Causality and Kramers-Kronig relations.

**Module 2 – Fundamentals of Antennas**
Interaction between electromagnetic field and materials.
Electronic polarization.
Material polarization.
Electronic, atomic/ionic, orientation, interface polarization mechanisms.
Lorentz model: derivation and discussion.
Drude model: derivation and discussion.
Magnetic response of natural materials.
Classification of magnetic materials.
Electrodynamic response of a magnetized ferrite.

**Module 3 – Receiving antennas and noise**
Artificial electromagnetic materials.
Historical perspective.
Concept of polarizability.
Electric and magnetic polarizability.
Polarizability of the omega metal particle.
Magnetoelectric effect.
Local field and interaction field.
From microscopic to macroscopic response.
Homogenization techniques.
Maxwell-Garnet formula.
Clausius-Mossotti formula.
Bruggeman formula.
Energy density for dispersive materials.
Causality and conservation of energy.
Anomalous dispersion.
Introduction to metamaterials.
Historical overview.
Metamaterials and their definitions.
Negative refractive index.
Artificial electric materials with negative permittivity.
Artificial electric materials in the visible.

Epsilon-near-zero metamaterials.
Natural and artificial magnetism.
Path to negative index material in optics.
Optical magnetism

**Module 4 – Propagation in free space**
Engheta resonator.
Pendry lenses.
Metamaterial transmission lines.
Miniaturized components.
Miniaturized antennas.
2D metamaterials: metasurfaces.
Design of metamaterial particles.
Design of metamaterial transmission lines and design of miniaturized components (unit cells, phase shifters, etc.).

**Module 5 – Introduction to Microwave Systems**
Electromagnetic invisibility.
Radar observability reduction.
Basic principles of EM invisibility.
Radar and cross-section scattering.
Figure of merit for EM cloaks.
Basic principles of EM transformation.
EM invisibility techniques.
Basic principles of scattering cancellation.
Scattering cancellation by volumetric metamaterials and metasurfaces (mantle cloaking).
Mie theory for spherical and cylindrical hidden objects.

**Module 6 – Electromagnetic Simulation Software (CST)**
Introduction to electromagnetic simulation of artificial electromagnetic materials and surfaces.
Generic electromagnetic simulation process.
Main electromagnetic simulation software.
Use of CST software.

## Evaluation system and criteria

The exam usually consists of a written test aimed at assessing the ability to analyze and rework the concepts acquired and a series of activities (E-tivities) carried out

during the course in virtual classes. The evaluation of the Etivity from 0 to 5 points is carried out, in itinere, during the duration of the course. The profit exam is evaluated for the remaining ones from 0 to 26.
The possible attribution of honors will be achievable by obtaining a score of 31/30, achievable by acquiring the maximum score in the profit exam and the maximum evaluation from the **Etivity**.

The written test includes 4 theory questions to be completed in 90 minutes. Each of the questions has a maximum score of 6.5 points.
The exercises in the exam tests will concern all modules from 1 to 6.

The student who must take the exam on the entire 6 CFU program may choose, indicating his choice during the exam, to take the exam through TWO PARTIAL EXAMS (see sample assignment uploaded on the platform).

- • Partial exam 1 (3 CFU) will concern the following modules: Module 1, Module 2, Module 3. Partial exam 1 will be evaluated up to a maximum of 13 points.
- • Partial exam 2 (3 CFU) will concern the following modules: Module 4, Module 5, Module 6. Partial exam 2 will be evaluated up to a maximum of 13 points.

**Bibliography and resources**

1. *Materials to consult*

The teaching material on the platform is divided into 6 modules. They cover the entire program and each of them contains handouts, exercises, slides, video lessons in which the teacher comments on the slides. This material contains all the tools necessary to deal with the study of the subject.

2. *Recommended bibliography*

Suggested readings are:

- Sergei Tretyakov, Analytical modeling in applied electromagnetics,
- Constantin Simovski, Sergei Tretyakov, An introduction to metamaterials and nanophotonics
- Andrey V. Osipov, Sergei Tretyakov, Modern electromagnetic scattering theory with applications