Teaching	Artificial electromagnetic materials
Level and course of study	Master's Degree in Electronic Engineering (LM-29)
Academic discipline (SSD)	IINF-02/A (ex ING-INF/02)
Academic year	2025-2026
Course year	1
Total number of credits	6
Prerequisites	Electromagnetic fields, guided propagation and microwave circuits
Teacher	Michela Longhi Faculty: Engineering Email: michela.longhi@unicusano.it Office hours: Consult the calendar on the following page of our website by checking the Videoconference times http://www.unicusano.it/calendario-lezioni-in-presenza/calendario-area-ingegneristica
Presentation	The course is designed to provide the methodologies and skills necessary 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 field disciplines and expands and deepens the knowledge acquired in the teachings of Electromagnetic Fields and Guided Propagation and Microwave Circuits, introducing new theoretical and applicative topics on artificial electromagnetic materials.
Disciplinary educational objectives	The course of Artificial Electromagnetic Materials has the following disciplinary educational objectives consequent to the specific objectives of the course of study: 1. Illustrate the relationships between the electromagnetic field and both natural and artificial materials 2. Describe artificial electromagnetic materials 3. Describe the main characteristics and applications of these materials 4. Teaching how to design an artificial electromagnetic material
Prerequisites	Knowledge of the fundamentals of mathematical analysis and multivariable vector functions. Knowledge of the fundamental properties of the electrostatic, magnetostatic and electromagnetic field. In this regard, it is advisable to review these notions, preparatory to learning and deepening the theory of propagation; to this end, it is possible to use the texts already consulted for the preparation for the basic exams of the mathematical area (Analysis I and Analysis II) and physics (General Physics II and Electromagnetic Fields) previously taken.
Expected learning outcomes	**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. It will also master the mechanisms of interaction between the electromagnetic field and natural/artificial materials and the physical quantities used to describe it. **Application of knowledge** 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 will have to be able to correctly interpret problems of analysis and design of these materials. At the end of the course, the student will have developed the analysis and characterization skills necessary to be able to choose and apply design techniques and tools to synthesize artificial electromagnetic materials and surfaces and will be able to recognize their main applications in different scientific and technological fields. **Ability to draw conclusions** At the end of the course, the student will have acquired the ability to choose and design an appropriate artificial electromagnetic material or surface for a specific application that meets certain design specifications. In addition, the student will have developed a critical ability to interpret the results obtained during a numerical exercise and a

	simulation both in terms of physical coherence of the results obtained and in terms of engineering feasibility of the identified solution. **Communication skills** At the end of the course, the student will have developed a correct and understandable 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. **Learning skills** At the end of the course, the student will have developed the ability to apply the acquired knowledge to the resolution of unfamiliar problems concerning the design of artificial electromagnetic materials or surfaces.
Course structure	The course is developed through pre-recorded audio-video lessons that compose, together with slides, handouts and exams carried out, the study materials available on the platform. Web-conference lessons scheduled in the calendar are also available during the teaching periods and video-receptions with the teacher to clarify any doubts. Interactive teaching is carried out in the "virtual classroom" forum and includes 2 Etivities that apply the knowledge acquired in the theory lessons. The Course of Artificial Electromagnetic Materials includes **6 credits (CFU).** The total study load for this teaching module is between 150 and 160 hours divided as follows: 1. approximately **130 hours** for viewing and studying videotaped material 2. approximately **20 hours** of interactive teaching for the elaboration and delivery of the Etivity 3. approximately **5 hours** of interactive teaching for the execution of self-assessment tests. It is advisable to spread the study of the subject evenly over a period of 6-8 weeks, dedicating between 20 and 25 hours of study per week.
Course programme	**Module 1 – Electromagnetic Field Reminders** (Week 1 – 20-hour commitment) Maxwell's equations and boundary conditions. Complex notation and polarization. Fundamental theorems. Vector potentials. Green function in free space. Hertz dipole. Radiation. Uniform/non-uniform electromagnetic waves. Phase and group speeds. Constitutive relationships and classification of materials (bi-anisotropic, anisotropic, bi-isotropic, isotropic): linear/non-linear, homogeneous/non-homogeneous, stationary/non-stationary, local/non-local, dispersive/non-dispersing materials. Constitutive parameters in the frequency and wavenumber domains. Kramers-Kronig causality and relationships. **Module 2 – Interaction between electromagnetic field and natural materials** (2 weeks – 25-hour commitment) 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 – Interaction between electromagnetic field and artificial materials** (Week 3 – 25-hour commitment) Artificial electromagnetic materials. Historical perspective. Concept of polarizability. Electrical and magnetic polarizability. Polarizability of the omega metal particle. Magnetoelectric effect. Local field and interaction field. From the microscopic to the macroscopic response. Homogenization techniques. Maxwell-Garnet formula. Clausius-Mossotti formula. Bruggeman's formula. Energy density for dispersing materials. Causality and conservation of energy. Anomalous dispersion. Introduction to metamaterials. Historical overview. Metamaterials and their definitions. Negative refractive index. Artificial electrical materials with negative permittivity. Artificial electrical materials in the visible. Epsilon-near-zero metamaterials. Natural and artificial magnetism. Path to negative index material in optics. Optical magnetism. **Module 4 – Introduction to Metamaterials and Metasurfaces** (Week 4 – 25-hour commitment) Engheta resonator. Pendry lenses. Metamaterial transmission lines. Miniaturized components. Miniature 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 – Electromagnetic Invisibility, Imaging and Sensing** (Week 5 – 25-hour commitment) Electromagnetic invisibility. Reduced radar observability. 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 for scattering cancellation. Dispersion cancellation through volumetric metamaterials and metasurfaces (mantle cloaking). Mie theory for spherical and cylindrical hidden objects. **Module 6 – CST Simulation Software** (Week 6 – 10-hour commitment)

	Introduction to electromagnetic simulation of artificial electromagnetic materials and surfaces. Generic electromagnetic simulation process. Main electromagnetic simulation software. Use of CST software. **Etivity 1** – Installation of CST STUDIO SUITE Student Edition and use of its interface (5 hours of study load - week 6). **Etivity 2** – Design and analysis of a simple structure within the CST Microwave Studio software (15 hours of study load - week 6).
Study materials	TEACHING MATERIALS BY THE TEACHER 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. Recommended texts: • 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
Assessment methods	The exam usually consists of a **written test** aimed at ascertaining the ability to analyze and rework the concepts acquired and a series of activities (E-activities) 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 exam is evaluated for the remaining **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 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 exams will cover all modules from 1 to 6. The student who has to take the exam on the entire 6 CFU program will be able to choose, indicating his choice during the exam, to take the exam through TWO PARTIAL EXAMS (see facsimile task uploaded on the platform). • The partial exam 1 (3 CFU) will cover the following modules: Module 1, Module 2, Module 3. Partial exam 1 will be evaluated up to a maximum of 13 points. • The partial exam 2 (3 CFU) will cover the following modules: Module 4, Module 5, Module 6. Partial exam 2 will be evaluated up to a maximum of 13 points.
Criteria for the assignment of the final paper	The assignment **of the final paper** will take place on the basis of an interview with the teacher in which the student will express his or her **specific interests** in relation to some topic he or she intends to deepen; there are no preclusions to the request for assignment of the thesis and there is no particular average to be able to request it.