UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Electromagnetic Radiation

2526-1-F1703Q046

Aims

This course aims to provide basic and advanced knowledge of the physics and technology of nonionizing electromagnetic radiation, with emphasis on the frequency range including radio waves and microwaves. Some topics related to specific applications, and health protection from the effects of electromagnetic radiation will also be covered.
At the end of the course the following objectives will be achieved:
Knowledge and understanding: Students will acquire in-depth knowledge of the physical principles of non-ionizing electromagnetic radiation, generation mechanisms, propagation and detection of radio waves and microwaves.
Applying knowledge and understanding: Students will be able to apply theoretical knowledge to analyze systems based on the emission and detection of electromagnetic radiation, evaluate technological solutions, and assess health protection issues.
Making judgements: Students will develop critical skills in interpreting experimental data and evaluating the suitability of different electromagnetic technologies for specific applications.
Communication skills: Students will be able to effectively communicate complex concepts related to electromagnetic radiation using appropriate technical language.
Learning skills: Students will acquire methodologies for autonomous updating on technological developments in the field of electromagnetic radiation and safety regulations.

Contents

Recalls of electromagnetism and waves. Plane waves in non-dissipative media. Reflection and transmission. Guided propagation. Transmission lines. Impedance coupling. S-parameters. Radiation sources and fields. Antennas. Diffraction. Systems of antennas. Radio communications technology. Interaction of radiation with matter. Aspects of health protection. Waves in plasmas. Ionosphere. Infrared radiation and its transmission in the atmosphere.

Detailed program

Historical background on the discovery of electromagnetic radiation. Electromagnetic spectrum. Ionization potentials. Ionizing and non-ionizing radiation.

Recalls of electromagnetism. Maxwell's equations. Faraday's law. Ampere-Maxwell's law. Gauss' laws for electric field and magnetic field. Potentials. Lorentz force. Constitutive relations in vacuum and in material media. Boundary conditions at interfaces. Current density. Charge conservation. Energy conservation and Poynting's theorem.

Recalls on the theory of wave propagation. Characteristic parameters of a sine wave. Dispersion relation. Phase and group velocities, and their physical interpretation.

Plane waves in nondissipative media. Forward and backward wave. Monochromatic waves. Characteristic quantities of monochromatic waves. Energy density and energy flux. Wave impedance. Linear, circular and elliptical polarization. Oblique propagation. Hints at waves in dissipative and inhomogeneous media.

Reflection and transmission perpendicular to the interface between two materials. Matrix representation of the fields. Wave impedance and reflection coefficient. Matrix formalism for propagation and scattering. Fresnel coefficients. Transmitted and reflected power. Case of a dielectric slab. Oblique incidence. Snel's laws. Total reflection and critical angle. Optical fibers.

Waveguides. Propagation model in hollow waveguides. TE and TM modes and their discretization. Propagation coefficient in guide and cutoff frequency. Phase and group velocities. Transverse components of the fields. Choice of guide dimensions. Characteristic impedance for TE and TM modes.

Two-conductor transmission lines. Distributed parameter model. Telegraphers' equations. Characteristic impedance. Propagation constant. Harmonic solutions. Physical meaning of characteristic impedance. Forward and backward waves. Reflection coefficient. Standing waves. Standing wave ratio. Input impedance. Attenuation along the line.

Maximum power transfer theorem. Coupling circuits. L, Pi and T circuits.

S-parameters. Measurement with a network analyzer. Input and output reflection coefficients. Smith's graph and its interpretation.

Electromagnetic potentials and gauge transformations. Lorenz gauge. Wave equations for potentials. Retarded potentials. Harmonic dependence: Helmholtz equations. Green's function and general solution to Helmholtz equations. Derivation of electric field and magnetic field from electromagnetic potentials. Fraunhofer approximation. Radiation vector. Radiation fields.

Definition of antenna. Equivalent circuit. Power density and radiation intensity. Isotropic radiator. Gain in directivity, gain in power and antenna gain. Radiation function. Cartesian and polar radiation diagrams. Use of radiation diagrams. Effective radiated power (ERP). Effective isotropic radiated power (EIRP).

Basics of linear antenna theory. Radiation intensity of a linear antenna. Hertzian dipole and Marconian dipole. Gain and radiated power of the Hertzian dipole. Hertzian antenna. Hertzian half-wave antenna. Marconian quarter-wave antenna. Travelling wave antennas. Loop antennas.

Huygens-Fresnel principle and its application to diffraction. Fresnel and Fraunhofer diffraction. Diffraction from single slit. Diffraction from circular aperture and Rayleigh's criterion. Diffraction from grating. Diffraction from obstacles and edges. Technological applications.

Theory of linear antenna systems. Arrays of parallel half-wave antennas. Study of the array factor in the case of equidistant antennas. Study of the array factor in the case of a uniform in-phase antenna system. Study of the array factor in the case of a uniform system of phase-shifted antennas. System of linear antennas with disuniform distribution of currents. System of antennas with high directivity.

Radio transmissions. Amplitude, frequency and phase modulation. Analog and digital coding. Personal telecommunication techniques: 1,2,3,4,5 generation systems.

Interaction of electromagnetic waves with matter. Phenomena of electrical polarization. Relative dielectric constant and its dependence on frequency. Application to body tissues. Lorentz model for dielectrics. Refractive index. Drude's model for conductors. Energy losses. Loss tangent. Plane waves in dissipative media. Attenuation. Skin depth. Propagation in dielectrics and conductors.

Specific Absorbtion Rate (SAR) and relationship with the power density vector. SAR in the human body. Physiological response to increased tissue temperature due to interaction with EM fields. Systemic and localized deterministic damage. Limitation system: guidelines, international and national regulations. Epidemiology and stochastic damage hypothesis.

Plasma. Electromagnetic description of plasmas. Calculation of constitutive parameters. Propagation of plane waves in a homogeneous plasma.

Propagation in an inhomogeneous and isotropic medium in very high frequency approximation. Propagation of radio waves in the ionosphere. Wave equations for an inhomogeneous medium. Formation of the ionosphere. The Earth-Sun system. Radio window.

Prerequisites

Knowledge of electromagnetism; general knowledge acquired during the three years of a technical-scientific bachelor's degree.

Teaching form

21 two-hour lectures delivered in face-to-face delivery mode ("modalità erogativa"), which will include where possible one or two seminar-style lectures delivered via videoconference by public and private sector experts.

Textbook and teaching resource

Documentation in slide format provided by the lecturer.
Classical electromagnetism textbooks (for example: J.D.Jackson, Classical Electrodynamics).
S. J. Orfanidis, Electromagnetic Waves and Antennas

Semester

Second semester

Assessment method

Oral examination, possibly supported by the voluntary presentation of a short in-depth text on topics similar to those of the course; possession of the knowledge provided and related skills and the ability to expound using correct language are evaluated.
There will be no partial tests during the course.
The examination will be held in Italian, or in English on request for Erasmus students.

Office hours

By appointment, to be defined by email with the course lecturer.
The contact details of the lecturers are as follows:
prof. Emilio Martines, U2 building, third floor, room 3026, email: emilio.martines@unimib.it

Sustainable Development Goals

GOOD HEALTH AND WELL-BEING | INDUSTRY, INNOVATION AND INFRASTRUCTURE | CLIMATE ACTION