MICRO-449

Applied Electromagnetics for Metamaterial Design

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Cursus	Sem.	Type
Génie électrique et électronique	MA1, MA3	Opt.
Génie électrique		Obl.
Microtechnique	MA1, MA3	Opt.
Photonics minor	H	Opt.
Photonique		Opt.

Langue d'enseignement	
Crédits	3
Session	Hiver
Semestre	Automne
Examen	Oral
Charge	90h
Semaines	14
Heures	**3 hebdo**
Cours	3 hebdo
Nombre de places	

Résumé

This course provides the students with the appropriate electromagnetics foundation to understand, model and design metamaterials, especially two-dimensional electromagnetic and optical structures such as metasurfaces. This course covers concepts that apply to both the microwave and optical regimes.

Contenu

1) Review of basic electromagnetic concepts
Electro- and magneto-statics, introduction to Maxwell equations, connection to circuit theory (capacitors, inductors), the wave equation in Cartesian coordinates, uniform and non-uniform plane waves, leaky waves, polarization decomposition, boundary conditions.

2) Wave scattering and propagation
Scattering at interfaces and homogeneous slabs, potentials, antenna theory (single antenna and antenna arrays), temporal and spatial dispersion, bi-anisotropy and chirality.

3) Electromagnetic theorems
Duality, volume equivalent currents, surface equivalence, energy conservation (Poynting theorem), momentum conservation (Maxwell stress tensor, forces and torques), reciprocity (Lorentz and Onsager-Casimir theorems), scalability of the wave equation, Krames-Kronig relations

4) Multipolar theory
Primitive Cartesian multipoles, symmetrization and detracing operations, irreducible multipoles, toroidal moments, anapole state, spherical multipoles, multipolar decomposition from the far-field and the near-field, Mie theory, Kerker effects.

5) Spatial symmetries in electromagnetics
Properties of the fields under reflection, rotation and parity operations, relation to multipolar effective material parameters, design strategies based on spatial symmetry breaking

6) 1D and 2D periodic systems
Diffraction gratings, subwavelength gratings, Rayleigh and Wood anomalies, guided mode resonances, Bravais lattices, conical diffraction

7) Homogenization of metamaterials
Effective medium theory, boundary conditions for metasurfaces, effective surface susceptibility modeling and synthesis

8) Field control strategies
Polarization control via wave-plates (birefringence) and chirality. Phase control via Gires-Tournois effect, electric and magnetic mode resonances, Pancharatnam-Berry effect, Detour phase. Generalized Snell law and perfect refraction.

9) Numerical python scripts
Several python scripts will be implemented during the course. This includes a transfer matrix method script to model

multilayer homogeneous and uniform slabs. A Fourier based angular propagation method for modeling the propagation of electromagnetic waves. A Mie scattering script for calculating cross-sections of spheres. A rigorous-coupled wave analysis (RCWA) script for simulating multilayer non-uniform 1D and 2D structures. Hologram generation using Gerchberg-Saxton algorithm.

Mots-clés

Electromagnetics, wave scattering, multipolar theory, metamaterials

Compétences requises

Concepts importants à maîtriser

Basic knowledge in electromagnetics and python programming

Acquis de formation

A la fin de ce cours l'étudiant.e doit être capable de:

- Modéliser and design a large array of metamaterial structures performing various operations
- Utiliser several python scripts to help them design electromagnetic systems
- Reconnaitre the theoretical concepts behind most contemporary concepts in the field of metamaterials
- Démontrer how these concepts are derived from Maxwell equations, how they can be used and extended

Méthode d'enseignement

Ex-cathedra courses and exercises

Méthode d'évaluation

The concepts discussed during the course will be evaluated via an oral exam at the end of the semester. The students are expected to explain these concepts, their origin and meaning, how they are derived from Maxwell equations and how they can be applied for modeling metamaterials. The students are not expected to remember all formulas by heart.

Ressources

Bibliographie

1. Rothwell, E.J. and Cloud, M.J., "Electromagnetics", CRC press, 2018.
2. Paknys, R., "Applied frequency-domain electromagnetics, John Wiley & Sons, 2016.
3. Kong, J.A., "Theory of electromagnetic waves", John Wiley & Sons, 1975.
4. Stutzman, W.L. and Thiele, G.A., "Antenna theory and design", John Wiley & Sons, 2012.
5. Ishimaru, A., "Electromagnetic wave propagation, radiation, and scattering: from fundamentals to applications", John Wiley & Sons, 2017.
6. Achouri, K. and Caloz, C., "Electromagnetic metasurfaces: Theory and applications", John Wiley & Sons, 2021.

Liens Moodle

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