Topic in Antenna & Micro Theory:
Artificial Electromagnetic Media and Metamaterials

ECE 770x
Fall 2014
Meeting Time: Friday 11:00-2:20
Meeting Place: Room EIT-3141

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1. Background:

Metamaterials are media composed of particles whose largest dimension is much smaller than the electromagnetic field wavelength in either free space or the ambient medium. These particles can be made of different shapes and using dielectrics, conducting material, or a combination of both. The intrinsic properties of each separate particle and the coupling between adjacent particles combine to produce a medium (the metamaterial) with properties that *cannot* be exhibited by naturally-occurring or traditional media that is engineered without any consideration of the fundamental electromagnetic dispersion phenomenon. By careful choice and design of the so-called metamaterial particles, the resulting metamaterial can be engineered to affect electromagnetic waves in a most atypical way giving rise to fascinating possibilities from cloaking to sub-wavelength imaging and electromagnetic energy harvesting.

While artificial dielectrics date back to the 1950s, the introduction of metallic particles as constitutive elements in creating metamaterials in the late 1990s reignited the interest in artificial media in general. Indeed artificial dielectric media are a type of metamaterial, but the introduction of metallic inclusions (or particles), such as the split-ring resonators amongst others topologies, created larger number of possibilities to control wave dispersion and the wave propagation characteristics in general.

The impact and sustained interest in metamaterial engineering are exemplified by the more than 2800 journal articles and more than 35 books dedicated to metamaterial, metamaterial design, modeling and applications. The reason for this high volume of publication and books on metamaterials, in a relatively short period of time, is attributed to the fact that metamaterial has become an enabling technology in a variety of technical fields and technologies including the following

1. Enhancing the performance of antennas
2. Sub-wavelength focusing
3. Imaging and lenses
4. Electromagnetic-based sensing modalities
5. Energy harvesting

6. Cloaking
7. Wave transformation
8. Material with enhanced (positive or negative) electrical and/or magnetic properties
9. Artificial magnetic material and artificial magnets
10. Magnetic optical material
11. Sensing and sub-surface detection

2. Course Coverage:

The field of metamaterials is multidisciplinary encompassing applied mathematics, fundamental electromagnetic physics, and elementary electrical engineering concepts. This course is *not* a survey of metamaterial application. The course covers the fundamentals necessary to understand metamaterial from the applied physics point of view and relevant tools necessary to design engineering applications with metamaterials. The concept of capacitance and inductance are revisited and the resonance in electrically-small structures is introduced from the quasi-static and electromagnetic (electro-dynamic) perspectives. Propagation in periodic structures is discussed with sufficient mathematics to enable full-wave analysis of periodic structures relevant to engineering applications such as electromagnetic and photonic band gap metamaterial. Definition of the constitutive parameters of electromagnetic media from both microscopic and macroscopic perspectives is discussed. Techniques for extraction of the constitutive parameters of metamaterials are discussed along with the fundamental constraints between these parameters dictated by pure energy conservation considerations. Some important applications of metamaterials will be presented with emphasis on the underlying physical principles relevant to each application.

Students enrolled in this course are expected to be familiar with fundamental undergraduate courses in electromagnetic engineering such as ECE 106 and ECE 375 or their equivalents, and undergraduate engineering mathematics courses. Course projects will require familiarity with one of the commercially available electromagnetic full-wave simulation tools such as HFSS, CST, COMSOL, FEKO or others.

3. Topics Covered

13 Lectures. One three-hour lecture per week (with 30 minutes break).
Total Instruction: 35 Hours

1. Meaning and definition of material electromagnetic properties
2. Fundamentals of wave propagation in regular and irregular media
3. Propagation in negative and positive media
4. Propagation in anisotropic and periodic media
5. Artificial media and negative media
6. Phase velocity, group velocity and dispersion and energy considerations
7. Dielectric and non-dielectric metamaterial particles
8. Material parameters extraction

9. Resonance
10. Quasi-static resonance
11. Application of metamaterial in energy harvesting and sensing
12. Near-zero media and its applications
13. Relationship between frequency selective surfaces and metamaterials

4. Course Material

1. *Lecture Notes*
2. *Assigned Journal Papers*

5. Grading

Projects: 50%; Final Exam: 50%

Prerequisite: First year course in electromagnetism physics, basic electronic circuits, fundamentals of electromagnetic engineering, differential calculus.