Metamaterials with Binary Constituents

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Digital electronics have led to a revolution in communications and signal processing. Using a discrete set of very few symbols (only two "bits" for binary systems) to encode any kind of information has drastically changed the way of communication. One of the most basic and powerful concepts of the digital representation of continuous quantities consists in the possibility of virtually symbolizing any value (namely any number) by only using two symbols, 0 and 1 in the classic binary Boolean algebra. In fact, a sequence of bits can in principle represent any number by using proper algebra and representation schemes.

Our present idea of metamaterials with binary constituents, or "digital metamaterials", is inspired by the concept of digital methods in the signal theory. In electromagnetics, often there is a need for materials with desired propagation characteristics, e.g., anisotropy, nonreciprocity, nonlocality, temporal and spatial dependence of the constitutive parameters, just to name a few, and the design and synthesis of such materials is often a challenging task. In some cases, even homogeneous materials, required for constructing materials with unconventional properties, e.g., media with very high dielectric constant at optical frequencies, may not be naturally available within the frequency range of interest. Our concept of digital metamaterials extends the concept of digitalization of the signals to electromagnetic materials with the aim at solving the above issues by using only two materials as binary constituents. Similarly to digital systems in electronics, where a sequence of only two binary digits, 0 and 1, can reconstruct any analog signal (with a proper signal processing), here using the notion of digital metamaterials, one can in principle reconstruct any variation of the electric and magnetic properties of a material, i.e., desired values of permittivity and permeability, by resorting to two basis materials as "bits" with two different epsilons (or two different mus). In other words, the goal is to explore how we can make a material with the desired value of epsilon (or mu) using only two materials. One of the important points in this idea is that the two media can be chosen according to their availability and suitability for the applications and the frequency range of interest. Eventually, the bulk effective behavior of the material may be reconstructed by the low-pass characteristics of the field propagation, which reduces the sub-wavelength variations in the material as the field propagates.

In this talk, several numerical case studies of the concept of digital metamaterials will be presented in order to highlight important features of this idea.