Wave Analysis, Characterization, and Applications of Metamaterials

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At present, a large body of electromagnetic research is based on the permeability of one (μ_r=1), except magnetic material. In 1968, Veselago published a paper discussing some peculiar electromagnetic characteristics in a medium with simultaneously negative values of μ_r and ε_r. This did not attract much attention until the late 1999's when Pendry, Smith and others actually produced a composite material with negative μ_r and ε_r. This material is now called NIM (negative index medium), NIR (negative index of refraction medium), LHM (left-handed medium), or DNG (double negative medium). This study spurred intensive research on metamaterials, which are artificial materials whose μ_r and ε_r can range from $-\infty$ to $+\infty$. The peculiar wave characteristics in this medium include negative refraction, phase and group velocities in opposite directions, Poynting vectors and wave number vectors pointing in opposite directions, large evanescent powers, and a possibility of focusing spot size much smaller that a wavelength. NIM is often highly dispersive and lossy. However, the use of left-handed transmission lines may point to metamaterials with less dispersion and low loss.

This lecture covers three important questions regarding metamaterials. First, we discuss the general analysis of wave characteristics in metamaterials, including phase and group velocities, Poynting vectors, loss and dispersion, reflection and transmission, and space-time wave packets. Several interesting wave phenomena are discussed, including backward surface waves and backward lateral waves. Secondly, we discuss how to construct metamaterials and the relationships between the constitutive relations and the physical geometries of inclusions in metamaterials, including bulk metamaterials and transmission line approaches. Thirdly, we discuss possible new applications of metamaterials, including plasmon sensors and focusing structures. Research on metamaterials is actively being pursued today, and new discoveries and applications are anticipated which may spur intensive new electromagnetic research in the future.