Restrictions and Limitations of Parameters in the Description of Complex Media

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The electromagnetic characterization of metamaterials is not very easily incorporated into the traditional machinery to analyze fields and waves in ordinary media. Especially the existence of backward waves and the fact that a wave can be refracted to the "wrong" direction requires that the material parameter values have to be reconsidered. Permittivity and permeability have to be negative. But this is counter-intuitive because we are used to thinking of permittivity (and permeability) as measures of electric (magnetic) energy density. Of course, one can respond to this and defend the possibility of such a behavior by observing that resonating elements can cause it in a limited frequency band through the plasma-type characteristics. This is a high-frequency phenomenon. And then, if the elements to resonate can be made sufficiently complex-shaped so that a resonance can be made to take place within small space, one can bring down the negative band into "low" frequencies.

If we have liberated our minds from the taboo of positivity of the permittivity and permeability, concerning its real part, one may ask are there any restrictions left that it should obey. And another natural question is what kind of limitations can be posed on the imaginary parts. Obviously the sign of the imaginary part of the refractive index is fixed for dissipative materials in order to avoid amplification in the energy. But does this lead to separate restrictions for the imaginary parts of permittivity and permeability? In the presentation, these questions will be discussed concerning both isotropic materials and also more complicated ones that may display anisotropy and/or magnetoelectric coupling.