Skewon–axion-based parametrization of bi-isotropic metamaterials

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Complex materials and metamaterials have occupied an important part in the present electromagnetics scene. One of the phenomena that carries media into these classes is magnetoelectric coupling. Such media are called bi(an)isotropic. In this presentation, we focus on a special class of bi-isotropic electromagnetic materials which display both non-reciprocal and chiral (handed) character.

The general linear bianisotropic electric/magnetic material response can be projected into an isotropic (not dependent on the direction of the exciting electric/magnetic field) subclass. This reduces the number of material parameters from 36 to 4. Of these four dimensions in the characterization of the properties, electric permittivity and magnetic permeability are present in the case of "simple" isotropic media; the two remaining ones can be separated basing on reciprocity. A reciprocal magnetoelectric medium is chiral (gauged with so-called Pasteur parameter), and the degree of non-reciprocity is measured with the Tellegen parameter (Lindell et al., *Electromagnetic Waves in Chiral and Bi-Isotropic Media*, Artech House, 1994).

In this presentation, we classify a three-dimensional subset of the space of bi-isotropic media in a new manner which gives intuitive meaning to the character of these media and complements the traditional constitutive description of electromagnetic materials. Instead of simple isotropic materials, we start the description from very extreme materials: axion medium and simple skewon medium (F.W. Hehl and Yu.N. Obukhov: *Foundations of Classical Electrodynamics: Charge, Flux, and Metric*, Birkhäuser, 2003). The axion medium is also known as PEMC (perfect electromagnetic conductor) which generalizes the concepts of PEC and PMC media, and is measured by the PEMC admittance. Axion is nonreciprocal and hence belongs to the class of Tellegen materials, although being an extreme form of such media. Analogously, the reciprocal counterpart of axion is the simple skewon medium, which is an extreme type of reciprocal chiral material. We show how these media can be seen to be parts of a three-parameter description of bi-isotropic material domain which also includes vacuum and unirefractive simple isotropic media as special cases. The three dimensions in this classification are the degree of magnetoelectrocity, nonreciprocity, and impedance.