Materials Science and Engineering Doctoral Defense

A Fundamental Model Methodology for the Analysis Design and Fabrication of a Narrow Transparency Window in a Bulk Meta-Material

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abstract

The optical valley of water, where water is transparent only in the visible range, is a fascinating phenomenon and cannot be modeled by conventional dielectric material modeling. While dielectric properties of materials can be modeled as a sum of Lorentz or Debye simple harmonic oscillators, water is the exception. In 1992 Diaz and Alexopoulos published a causal and passive circuit model that predicted the window of water by adding a "zero shunt" circuit in parallel with every Debye and Lorentz circuit branch. Other than the Diaz model, extensive literature survey yielded no universal dielectric material model that included water or offered an explanation for this window phenomenon. A hybrid phenomenological model of water, proposed by Shubitidze and Osterberg, was the only model other than the Diaz-Alexopoulos model that tried to predict and match the optical valley of water. However, we show that when we apply the requirement that the permittivity function must be a complex analytic function, it fails our test of causality and the model terms lack physical meaning, exhibiting various mathematical and physical contradictions. Left with only the Diaz proposed fundamental model as the only casual model, this dissertation explores its physical implications. Specifically, the theoretical prescription of Kyriazidou et al for creating artificial dielectric materials with narrow band transparency is experimentally demonstrated for the first time at radiofrequencies. It is proposed that the most general component of the model of the frequency dependent permittivity of materials is not the simple harmonic oscillator but rather the harmonic oscillator augmented by the presence of a zero shunt circuit. The experimental demonstration illustrates the synthesis and design of a new generation of window materials based on that model. Physically realizable Lorentz coatings and RF Debye "molecules" for creating the desired windows material are designed using the full physics computational electromagnetic code. The prescribed material is then implemented in printed circuit board technology combined with composite manufacturing to successfully fabricate a lab demonstrator that exhibits a narrow RF window at a preselected frequency of interest. Demonstrator test data shows excellent agreement with HFSS predictions.

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