Concurrent Design of Conductor Shape and Artificial Material Composites for RF Applications

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Design optimization for electromagnetic applications has traditionally been a process based on the creativity, past experience and knowledge of the designer. It has thus focused mostly on shape design or geometry of the device for performance improvement. Recent advances in fast and rigorous full wave simulators and the concurrent availability of inexpensive manufacturing techniques for intricate shape and composite materials provided the opportunity to revolutionize traditional design optimization processes to topology and material optimization. When compared with more conventional optimization, where the topology of the device is assumed a priori and remains fixed, topology optimization offers much more degrees of freedom. Consequently, it is reasonable to expect that designs resulting from topology optimization have novel configurations with much higher performance. This has been demonstrated by designing for artificial material composites via integrating topology optimization methods with Finite Element Boundary Integral (FE-BI) methods to generate "new" electromagnetic devices that exhibit new properties and significantly better performance. Specifically, studies showed that properly designed dielectrics or a combination of different materials can lead to designs which have greater bandwidth and small size. Nevertheless, the focus so far has been on the dielectric material substrate of narrowband antennas and on two constituent compositions such as high contrast ceramic-polymer mixtures for pre-chosen antenna geometries. In this paper, our goal is to optimize the metamaterial profile concurrently with the conductor topology to achieve further antenna performance enhancements by exploring all possible design degrees of freedom. For that goal, we introduce the mathematical framework for optimizing the conductor topology and material distribution of dielectric substrates using the Solid Isotropic Material with Penalization (SIMP) method. As an example, the SIMP method is extended here to design the conductor topology and dielectric material distribution of a SATCOM antenna subject to pre-specified bandwidth and miniaturization criteria. To our knowledge, this is the first ever integration of combined shape and material optimization for performance improvement of RF applications. A key element of this extension is the use of the latest fast algorithms recently introduced in the FE-BI formulation. For design optimization, the Sequential Linear Programming and an exact sensitivity analysis based on the solution of the adjoint problem for both conductivity and dielectric permittivity is employed. The sensitivity analysis is crucial to integrating the solver with the Sequential Linear Programming optimizer. Despite challenges introduced such as increased number of design variables and ill-conditioned solution matrices the proposed technique allowed a substantial increase in the bandwidth of an irregular shaped SATCOM antenna on a high contrast substrate. As demonstrated by the design example, by virtue of the generality and efficiency of the proposed method, there is great potential for improving antenna performance or other RF devices from scratch.