Adjoint-based Design Optimization of MIMO Metamaterial Devices

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In this work, an inverse design method for multi-input multi-output (MIMO) metamaterial devices is developed. Inverse design problems are often difficult to solve directly and require different approaches such as heuristic methods or design optimization to find a solution. Recently, it has been shown that the solution of large-scale inverse design problems is possible through the use of adjoint methods (Yablonovitch et. al., "Adjoint shape optimization applied to electromagnetic design," Opt. Express 21, 21693-21701 (2013)). Here, a fast, forward solver is developed and used together with an adjoint-based optimization routine to solve inverse metamaterial design problems.

In previous work, MIMO metamaterial devices were realized using a heuristic method (G. Gok and A. Grbic, "A printed antenna beam former implemented using tensor transmission-line metamaterials," in *Proc. IEEE Antennas Propag. Soc. Int. Symp.*, Jul. 2014, pp. 765–766). This MIMO design procedure is limited to designing devices that behave as lenses, so the designed metamaterials suffered from phase errors for all but one input/output pair. To tackle these issues, an optimization-based approach was demonstrated in (B. B. Tierney and A. Grbic, "Designing Anisotropic Inhomogeneous Metamaterial Devices Through Optimization", *Antennas and Propagation IEEE Transactions on*, vol. 67, no. 2, pp. 998-1009, 2019.). It utilized a finite element method solver for the forward problem, making optimization of large devices computationally intensive and time consuming. This work introduces a fast 2-D frequency domain solver for grids of admittance (Y-parameter) matrices which is suitable for the design of electrically large devices. The design of devices that possess large numbers of design variables is further accelerated by coupling the frequency domain solver to an adjoint-based constrained optimization routine to find candidate metamaterial designs. To ensure that the candidate designs correspond to physically realizable structures, full-wave models of the unit cells are developed and used directly in the optimization routine.

To demonstrate the utility of this proposed method, a planar metamaterial beamforming network with five input ports and five different aperture fields was designed. The beamforming network is comprised of microstrip-based, transmission-line metamaterial unit cells that have variable widths and lengths. Results for the beamforming network will be shown at the conference.