Advances in Transformation Electromagnetics Devices Based on Tensor Impedance Surfaces

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The transformation electromagnetics design method (J. B. Pendry, et. al, Science, 23, 1780-1782, 2006) has been used to devise innovative microwave and optical devices such as beam-shifters, field-rotators, collimators, and invisibility cloaks. Transformation electromagnetics allows an initial field configuration to be transformed to a desired one via a change in material parameters (ε and μ) prescribed by a coordinate transformation. The transformed materials are generally anisotropic and inhomogeneous and can be represented as tensors. Along with volumetric designs, planar transformation-based devices using transmission-line networks have also been pursued for controlling 2D wave propagation (G. Gok and A. Grbic, T-MTT, 61-4, 1414-1424, 2013).

In previous work, a method was introduced for designing planar transformation electromagnetics devices that control surface waves using tensor impedance surfaces (TISs), where the tensor surface impedance, $\overline{\overline{\eta}}_{surf}$, is the quantity used to describe anisotropic properties rather than material parameters $\overline{\overline{\varepsilon}}$ and $\overline{\overline{\mu}}$. A beam-shifting surface was designed and simulated (A. Patel and A. Grbic, T-MTT, 62-5, 1102-1111, 2014).

The guidance properties of TISs have been studied in the past (H. J. Bilow, T-AP, 51-10, 2788-2792, 2003). More recently, power flow along TISs has been investigated (F. Elek and A. Grbic, APSURSI 2014, 763-764, 2014). Transforming the surface admittance in a manner analogous to material parameter transformations, necessarily results in the transformation of all space. Therefore a method was devised for controlling surface-waves, where it is critical to not transform the free space above the TIS, but rather the TIS alone. The method requires iteratively solving for the $\overline{\overline{\eta}}_{surf}$ that simultaneously satisfies three expressions: the TIS dispersion equation, the power flow equation, and a determinant condition.

In this work, surface-wave versions of well-known transformation electromagnetics devices (that are more complex than the beam-shifter designed in previous work) are presented. New insights and limitations of the method are revealed. Compact, closed-form design equations are derived that allow the spatially varying $\overline{\overline{\eta}}_{surf}$ (that supports a desired transformation electromagnetics design) to be found directly, without iteratively solving the aforementioned three expressions. The design equations are powerful in that they may be used to implement metasurfaces with arbitrary phase and power distributions- ones that need not result from standard transformation electromagnetics coordinate transformations.