Beam Shaping with Metamaterial Huygens' Surfaces

Carl Pfeiffer* and Anthony Grbic
Department of Electrical Engineering and Computer Science,
University of Michigan, 1301 Beal Ave, Ann Arbor, MI, USA

Metamaterials have demonstrated the ability to manipulate electromagnetic waves with unprecedented control. However, their notable thickness often leads to significant loss and fabrication challenges. This has motivated the development of metasurfaces: the two dimensional analog of metamaterials. Here, a new type of metasurface, referred to as a metamaterial Huygens' surface, is introduced. Metamaterial Huygens' surfaces are capable of arbitrarily manipulating electromagnetic wavefronts without reflection. These surfaces will likely find a wide range of beam shaping applications including: single-surface lenses, polarization controlling devices, stealth technologies, and perfect absorbers.

This work is related to a recent research effort on beam shaping with metasurfaces. In (N. Yu, et al. Science, 2011), beam shaping was achieved with an array of V-antennas that provided a phase gradient across a surface. However, the reported metasurface exhibited a purely electric response, which necessarily resulted in significant reflection. In contrast, the proposed metasurfaces exhibit both an electric and magnetic response. Therefore, they can be designed to be reflectionless.

Metamaterial Huygens' surfaces are so named because their design is based upon a rigorous formulation of Huygens' principle: the Surface Equivalence Principle. Given independent field distributions in two regions of space, the Surface Equivalence Principle can be invoked to determine the necessary electric and magnetic currents that satisfy the boundary condition between the regions of space. Here, we realize these surface currents with a nonuniform distribution of subwavelength scatterers having both electric and magnetic sheet impedances/polarizabilities. These scatterers provide a desired transmitted field in one region while creating zero reflected field in the other. In the design process, the electric and magnetic sheet impedances (or alternatively electric and magnetic polarizabilities) are computed by taking the ratio of the currents and the tangential fields along the surface. These impedances are then realized as metallic patterns on a dielectric substrate.

A proof of concept Huygens' surface was designed that refracts a normally incident plane wave to an angle of 45° from normal. The electric response is realized with loaded strips and the magnetic response is realized with split-ring-resonators. This structure was fabricated by stacking 58 identically patterned printed-circuit-boards, and measured with a near field scanning system. The half-powered bandwidth and peak efficiency were measured to be 24.2% and 86% respectively, which closely agreed with simulations.