Additive Manufacturing of Luneburg Lens Antennas Using Space-Filling Curves and Fused Filament Fabrication

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Structures with spatially graded dielectric properties, also known as graded-index (GRIN) structures, have been used for a wide variety of practical engineering applications. For example, in photonic systems GRIN structures are a common component used as focusing lenses and collimators for coupling light into optical fibers. A Luneburg lens is a spatially-graded spherical structure in which every point on the surface is the focal point of a plane wave incident from the opposing surface. One of the main practical challenges to using Luneburg lenses for antenna applications, or for that matter any GRIN structure, is the ability to fabricate the graded permittivity distribution using a cost-effective and robust approach. In this work, we demonstrate a new method for realizing Luneburg lens antennas with nearly continuously graded permittivity profiles in three dimensions. The method combines fused filament fabrication, a nearly ubiquitous additive manufacturing technique, with an effective media approach that employs space-filling curves. The primary benefits of this approach over previously reported techniques are that it does not require the use of support material during printing, and the printable materials have low electromagnetic loss. We experimentally validate our design methodology by fabricating and characterizing two Luneburg lenses designed to operate at separate frequency bands (26-40 GHz and 70-110 GHz). The antenna gain of the 26-40GHz lens is greater than 20 dBi across the entire band, and the 70-110GHz lens has greater than 24 dBi of gain throughout its band. The results demonstrate good agreement with rigorous electromagnetic simulations. We also demonstrate the ability to passively beam steer with minimal loss in performance.