Additively Manufactured Luneburg Lens based Conformal Beamformer

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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. At microwave frequencies, GRIN structures have been explored for applications such as microwave lenses and beam-steering antennas. Out of the variety of different GRIN distributions that have been explored for antenna applications (e.g. half Maxwell fisheye, Eaton, Luneburg), the Luneburg lens is probably the most well-known. 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. Its popularity for antenna applications stems from its broadband nature, potential for high gain, and its ability to form multiple beams. The ability to form multiple beams, in particular, makes it an attractive choice for beam-scanning applications such as high-frequency wireless communication and low-cost directional finding. The original Luneburg lens has a relative permittivity distribution given by $\varepsilon_r = 2 - (r/R)^2$ where r is the radial distance from the center of the lens and R denotes the sphere radius.

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. The fabrication of structures with three-dimensionally-varying electromagnetic (EM) properties using traditional manufacturing techniques is not trivial. A new promising approach to realizing graded-index structures, such as the Luneburg lens, is the use of additive manufacturing (AM). Here AM is used to create small scale variation in a base material, most often a polymer. This small scale (i.e. much less than the wavelength) material variation results in an effective local permittivity which is a function of the local volume fraction of printed material to air. By varying the material volume fraction spatially a graded permittivity distribution results. In this presentation, we will present an AM methodology for realizing Luneburg lenses using fused-deposition modeling (FDM). FDM is a very common and cost-effective AM approach that prints low loss thermoplastics such as polycarbonate. It is difficult, however, to print spherical objects using FDM. Consequently, it is desirable to transform the spherical Luneburg lens geometry into a geometry more conducive for FDM printing. A transformation optics approach can serve this purpose. By using quasi conformal transformation optics approach, one surface of the original Luneburg lens is modified into a cylindrical or flat surface that is more attractive for FDM printing as well as for the introduction of antenna feeds.

In this presentation we will present the design methodology to obtain the modified dielectric distribution profile using COMSOL multiphysics finite element based 2D numerical solver. Sample devices, designed at Ku-band, were then fabricated using a high-end FDM printer (nScrypt 3Dn-300) and experimentally characterized. The experimental results, which agreed well with predictions, will be presented.