Luneburg Lens Created from Distributed Water Cylinders

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Abstract—In this work, a Luneburg lens operating at 15 GHz is created from water cylinders. The approach uses effective media of water and an iterative dielectric distribution method to achieve the Luneburg lens electromagnetic profile. From the approach, the focusing of energy using the proposed Luneburg lens is shown numerically. While the approach is successfully creates a luneburg lens, the losses due to the water significant.

I. INTRODUCTION

While Luneburg lenses are a well established lens design concept [1], [2] new and innovative methods for creating these structures are still being pursued [3]. A Luneburg lens is a cylindrical or spherical lens in which the focal point of any incoming plane wave is at the opposite edge of the lens. Inversely, if a point source is located at the edge of the lens, a plane wave is created at the other side. This inherently makes a Luneburg lens a useful passive element for directional radiation or remote sensing. Luneburg lenses are typically made from solid material, since the solid material is used to modify the effective electromagnetic properties inside the lens. This work examines the possibility of using liquid structures to create a Luneburg lens. One distinct advantage is the ability to leave vacant space, no solid material, while the antenna system is not operational. Another advantage is the potential to vary the effective media for different operational modes depending on the liquid used. These advantages are predicated on the fact that liquid can flow, while a solid structure can be only one configuration. One disadvantage that will be shown is the power loss due to the inherent loss character of water at radio frequencies. For this work, a Luneburg lens was designed using water cylinders as the only materials to modify the spatial distribution of the effective permittivity. The ability to create passive electromagnetic structure which is reconfigurable could be beneficial for various applications and at the very least is an interesting method to create a Luneburg Lens.

II. DESIGNING A WATER CYLINDER LUNEBURG LENS

The design of the water cylinder Luneburg lens consists of three parts. The first is calculating the dielectric constant of the water. The second is establishing the effective property relationship between volume fractions. The third is locating the cylinders to create a Luneburg distribution. These three steps result in a water cylinder Luneburg lens. Dielectric properties of water vary with respect to salinity and temperature. Great lengths have been taken to model the dielectric properties of water given the salinity and temperature parameters. [4], [5] developed a model that characterized water from 1-100 GHz including salinity and temperature. This model is applied to the water cylinders. The effective properties of infinitely long cylinders are well established [6]. A well-known and commonly used effective media approximation for long cylinders is Maxwell Garnett. While the MG mixture formula is not perfect, the calculated permittivity tends to have small errors [7]. The accuracy of the mixture formulas can be improved on a case-by-case basis. For this work we applied MG for infinite cylinders with a depolarization factor of N=0 for electric field parallel to the length of the cylinder and N=0.5 for electric field perpendicular to the length of the cylinder. A depolarization factor of N = 0 is effectively a volume fraction ratio between the host dielectric, in this case air, and the inclusion dielectric, in this case water.

Good et al method [8] of spatial varying dot distribution was modified to distribute the water cylinders. The advantage of this method is uniformity and the fact that the distribution does not need to be initially discretized. Good et al method begins with a cylinder, located at the center and iteratively determines the appropriate number of cylinders and location of the next segment of the graded dielectric distribution. When the iterative approach is finished, the cylinder distribution should accurately replicate the desired dielectric distribution. A more detailed description can be found in [8].

III. NUMERICAL VALIDATION AND DISCUSSION

After the cylinder distribution was determined, the water cylinder Luneburg lens was simulated in Ansys High Frequency Structural Simulator (HFSS). A design frequency of 15 GHz and radius of 150mm were chosen to facilitate eventual physical modeling. The simulation consisted of a plane wave incident on the Luneburg lens from the -x direction. The top and bottom of the simulation were set to periodic boundary conditions. The sides of the simulation were set to radiation boundary conditions. The electric field was sampled along the xy plane to determine the effectiveness of the Luneburg lens. The real part of the electric field and the magnitude of the electric field is shown in Figure 1.
Fig. 1. The real part (a) and magnitude (b) of the electric field of a plane wave incident on the water cylinder Luneburg lens.

Since energy is focusing at the edge of the Luneburg lens, the water cylinder distribution is guiding the field appropriately. There are two issues that arise from this simulation. First, a defocusing occurs due to the inability of [8] to achieve a near unity dielectric constant. Second, energy is lost due to dispersion in the water. An interesting feature from this dispersion is the narrowband character of the structure. Even with these issues, the water cylinder can resemble a Luneburg lens.

IV. Conclusion

In this work, a water Luneburg lens was described and numerically demonstrated. Future work will build and experimentally validate the numerical simulation. The use of liquids instead of solids could offer unique potential for graded structures such as the Luneburg lens shown in this work.

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REFERENCES