3D Modeling of Transformation Optics based Flattened Luneburg Lens using COMSOL Multiphysics® Modeling Software

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INTRODUCTION: Luneburg lens is a spatially varying spherical dielectric lens and widely used for its wideband nature, ability to form multiple beams and low cost. The spherical shape of the lens often makes it inconvenient to integrate with feeding networks and transformation optics based flattened luneburg lens makes the antenna and waveguide integration easier for integrated RF structure. Conventionally, 2D modeling with line current excitation has been commonly used as a convenient means to study the beamscanning capability of the modified luneburg lens[1-2], but 3D full wave simulation provides a more appropriate approach to calculate and predict the lens' beamscanning angle, 3D radiation pattern and realized gain.

3D Luneburg Lens Profile

$$\varepsilon(r) = 2 - \left(\frac{r}{R}\right)^2, \mu = 1$$

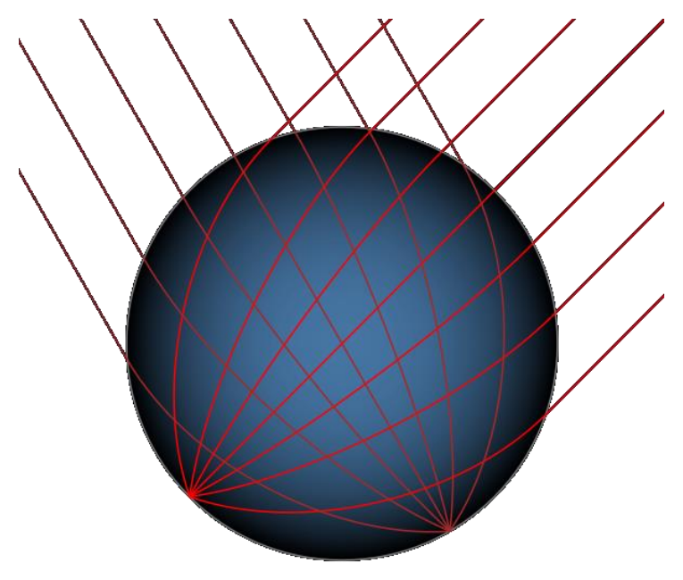

Figure 1. Beamforming nature

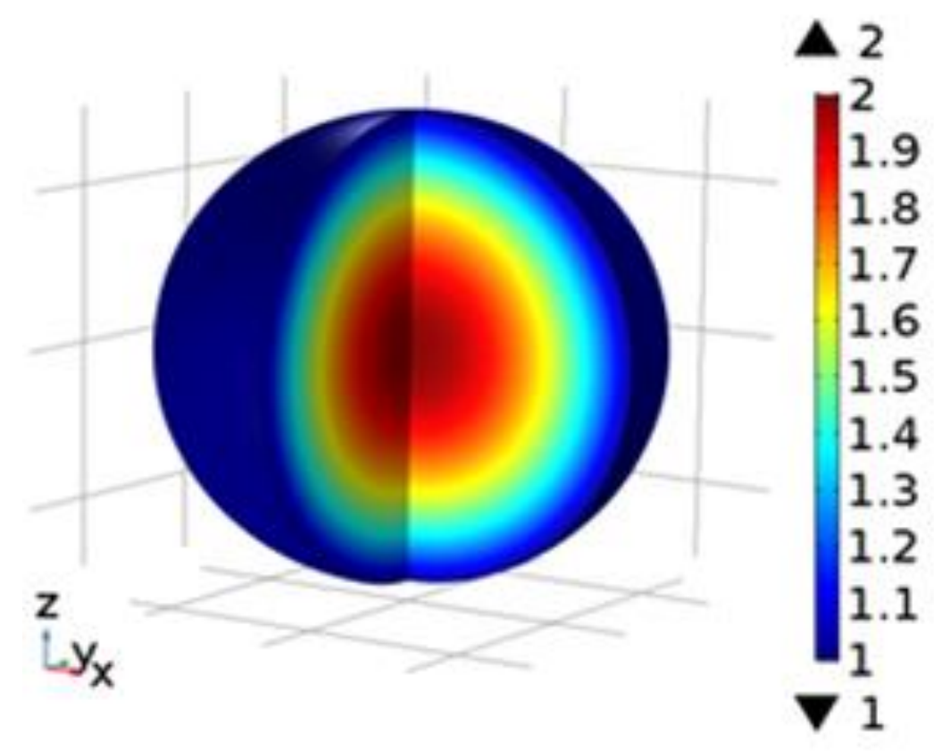

Figure 2. 3D Luneburg Lens

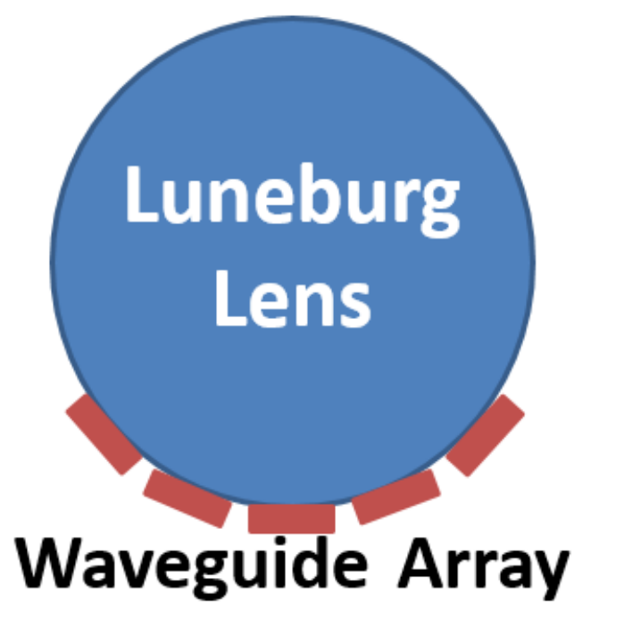

Figure 3. Feeding Mismatch

COMPUTATIONAL METHOD: The 3D modeling and simulation were done using COMSOL RF module. COMSOL software is suitable for performing the coordinate mapping and axisymmetric rotation of 2D datasets. The governing equations used for the constitutive parameters calculation are as follows:

$$\varepsilon^{m'n'} = \frac{J_m^{m'} J_n^{n'} \varepsilon \delta^{mn}}{|J|}, \mu^{m'n'} = \frac{J_m^{m'} J_n^{n'} \mu \delta^{mn}}{|J|}, J_\kappa^{\kappa'} = \frac{\partial x'^\kappa}{\partial x^\kappa}$$

$J_K^{K'}$ is the jacobian matrix of coordinate transformation and δ^{mn} is the Kronecker delta function. ε and μ are the permittivity and permeability of the original luneburg lens. The 3D modeling was performed in two steps:

FIRST STEP: The quasi-conformal mapping of the 2D luneburg lens was done using dirichlet and sliding boundary conditions and 2D permittivity distribution was calculated (Figure 4). To generate the 3D profile, the 2D datasets were revolved by 360˚ along its center axis (Figure 5) and exported;

SECOND STEP: The exported datasets produced in previous step was imported and defined as the material permittivity for a new 3D model with same dimensions. The new model was considered as non-magnetic.

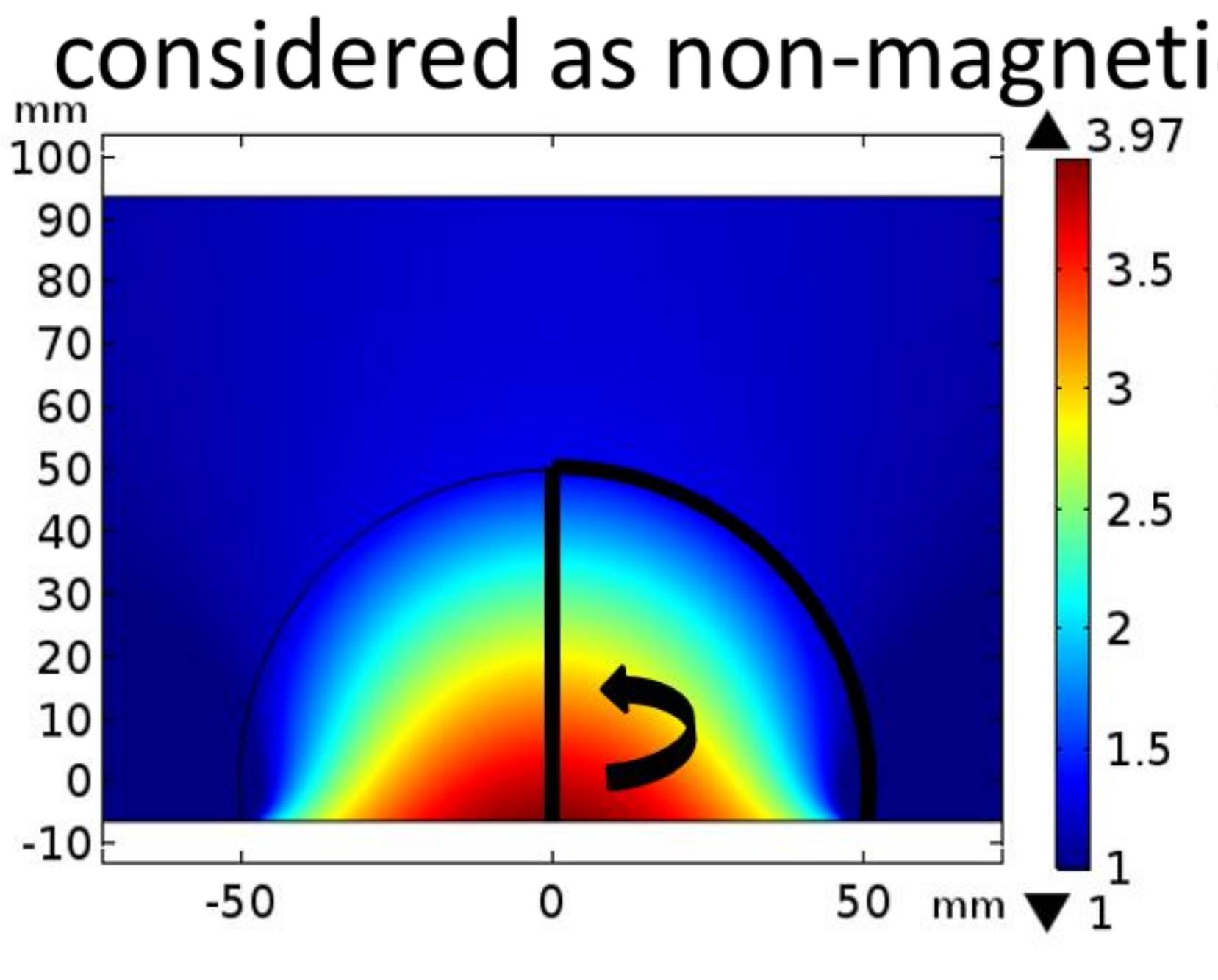

Figure 4. 2D Modified Luneburg Lens permittivity distribution

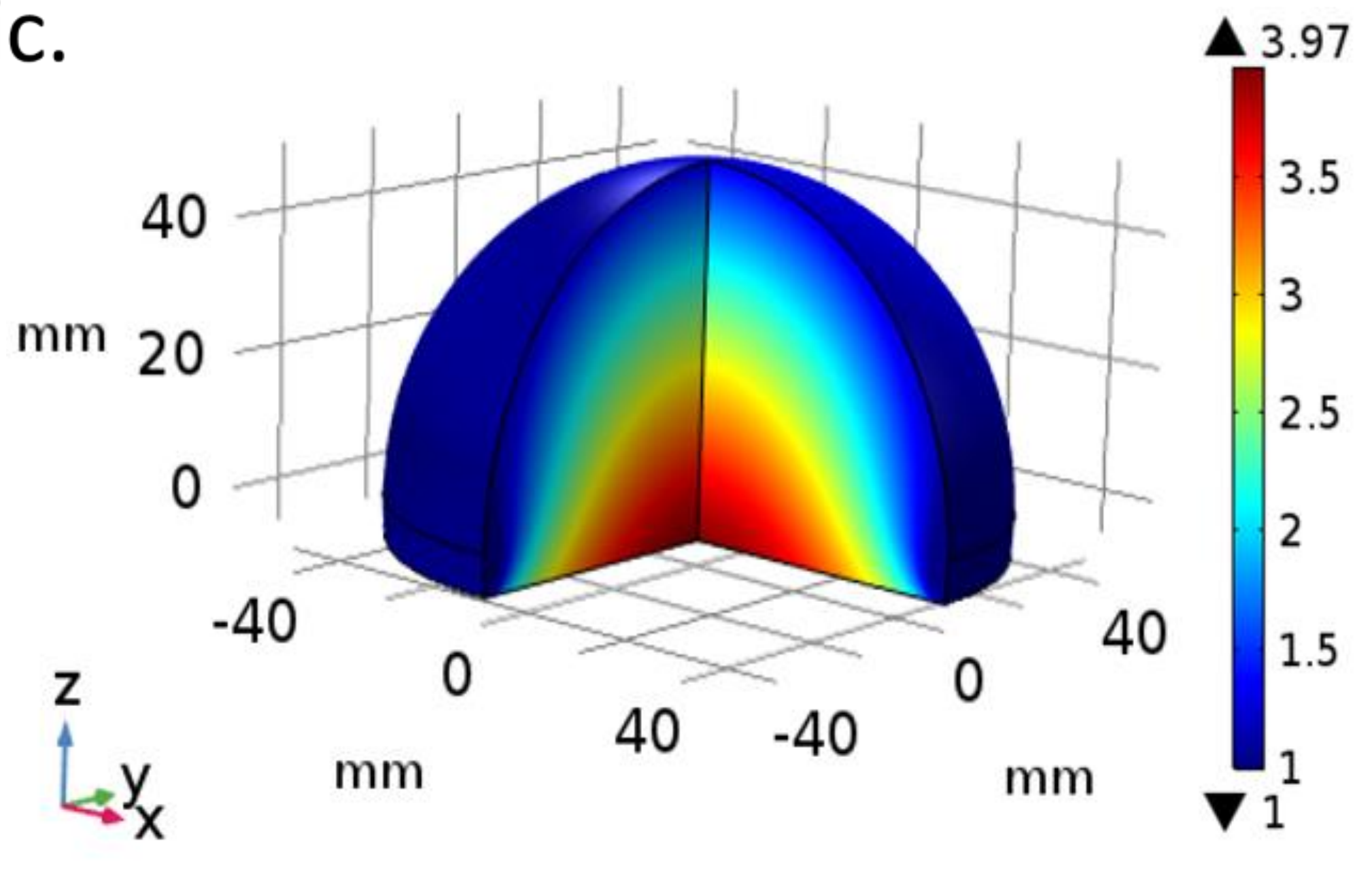

Figure 5. 3D Modified Luneburg Lens permittivity distribution

SIMULATION MODEL SETUP:3D full-wave electromagnetic simulation was performed using waveguide excitation at the flat portion of the modified luneburg lens. Perfectly Matched Layer (PML) boundary condition was applied all around to minimize the outward reflections.

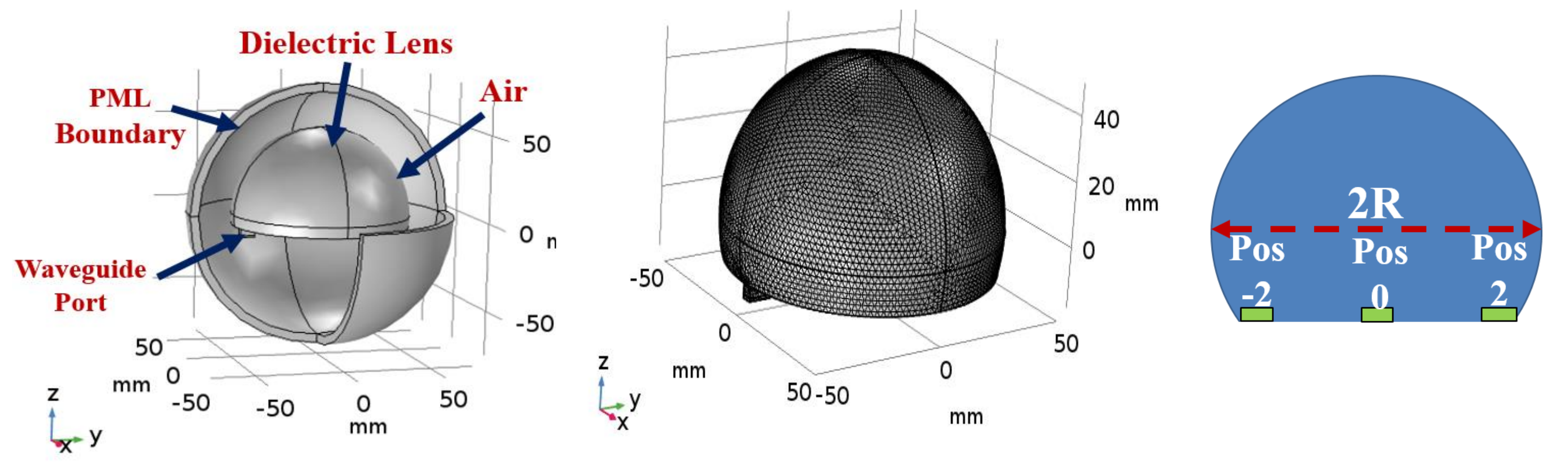

Figure 6. 3D Model Simulation Setup (R = 50mm)

SIMULATION RESULTS: To predict the electromagnetic function of the modified 3D luneburg lens, we excited the flat portion of the lens with an open-ended waveguide at three different locations (Figure 6) and observed the 3D radiation pattern, far field gain(dBi) and beamscanning angle(degree).

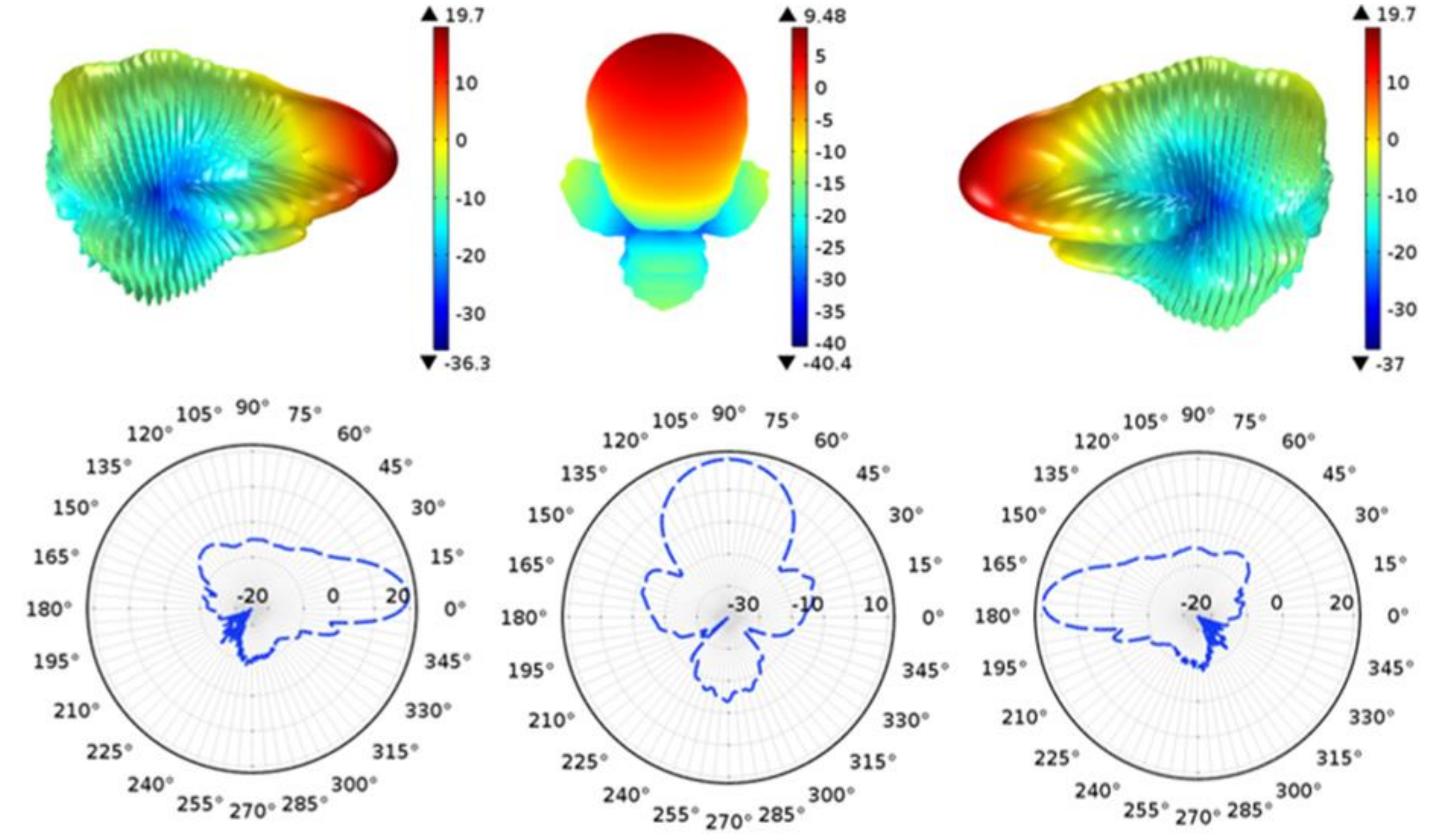

Figure 7. 3D and 2D Radiation pattern of the modified Luneburg lens at 30GHz operating frequency with excitation position at pos -2, pos 0, pos 2

CONCLUSIONS: In this work, we showed the 3D modeling approach of the modified 3D luneburg lens to predict the 3D radiation pattern, far-field gain and beamscanning angle. The model shows a beamsteering capability from -85˚ to +85˚ with a varying gain at different excitation positions. The gain exhibits decreasing nature from outward edges to the center of the lens due to the impedance mismatch seen by the waveguide at different locations. The mismatch is higher at the center due to larger permittivity value and becomes smaller at the edge which has a permittivity value of free space. The modeling approach was validated using 3D printing fabrication [3-4] for an example lens. The simulation results following this approach complied well with experiments.

REFERENCES:

1. Do-Hoon Kwon,"Quasi-Conformal Transformation Optics Lenses for Conformal Arrays," IEEE Antennas and Wireless Propagation Letters, Vol. 11, 2012.
2. Liang Liang, and Sean Victor Hum," Realizing a Flat UWB 2-D Reflector Designed Using Transformation Optics," IEEE Transactions on Antennas and Propagation, Vol.62, No.5, May 2014.
3. Soumitra Biswas, Mark S. Mirotznik, "Customized shaped Luneburg Lens Antenna Design by Additive Fabrication", 2018-18th International Symposium on Antenna Technology and Applied Electromagnetics, University of Waterloo, Waterloo, ON, Canada, Aug 19-22, 2018.
4. Soumitra Biswas, Zachary Larimore and Mark Mirotznik," Additively Manufactured Luneburg Lens based Conformal Beamformer", 2018 IEEE International Symposium on Antennas and Propagation (APS/URSI), Boston, MA, USA, July 8-13, 2018.

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