RESEARCH ARTICLE OPEN ACCESS

An Optimized Luneburg Lens Antenna Design for Validating Radiating Gain Stability in Beam Switching

Deepthi KVBL[1] and Dr. K. Jaya sankar[2]
[1]*Department of Electronics & Communications Engineering, MVSREC, Hyderabad*
[2]*Department of Electronics & Communications Engineering, MGIT, Hyderabad*

ABSTRACT
An optimized meta-material Luneburg lens is considered for validating the stability aspect of gain for applications involving beam switch feature. The objective is minimizing adjacently spaced beam transitional region while offering adequate gains for each field angle. The approach is to start with a regular Luneburg lens and then alter its dielectric properties electrically and geometrically. For successfully validating the concept, the design is simulated and the results are compared with the pre-existing measured benchmarks.

KEYWORDS
Luneburg lens, beam switching, PSO, gain stability, beam-forming.

Date of Submission: 02-03-2022 Date of Acceptance: 16-03-2022

I. INTRODUCTION

In the communication systems [1] involving higher radiating gains for compensating the EM wave propagating losses in the medium (air) [2], which are severely prevalent at microwave frequencies, the traditional implementation of antenna arrays is very challenging due to the power losses in beam forming networks. Hence, antennas producing multiple beams preferably offer solutions with highly directional beams with easy switching more economically. Owing to the positional and orientation dynamics, multi-beam radiations [3], [4] involving vertically broader & horizontally narrower is deployed as it can offer the gain sufficiently with nearly uniformly gain response. The Luneburg lens antennas [5]-[7] with rotational symmetry can cater to offer similar gain for each beam in a broader frequency band with respect to reflection coefficient and nature of radiation behaviour. Inadequate gain prevails at the transition region causing unstable power due to frequented handovers [15]. This Paper presents the lens design with Particle Swarm Optimisation (PSO) and validates the uniform radiating gain pattern with the existing measured beam-switching gain patterns.

II. DESIGN OF LUNEBURG LENS FOR BEAM PATTERN OPTIMISATION

An Inhomogeneous spherical Luneburg lens exhibiting variations in relative permittivity as in [5]-[7], [9]-[11] is

$$\varepsilon_r(r) = 2 - (r/a)^2 \quad (1)$$

r indicates distance (radially measured) & a is radius of sphere. It has slab of dielectric material sandwiched with a set of metallic plates and the dielectric is obtained by specific number of uniformly equi-centered dielectric rings of varying width as depicted in Fig.1. The width and relative permittivity value of each dielectric slab is obtained with optimization scheme in accordance with various mechanisms described in [12]-[17]. The drop in gain is worst when the neighbourhood feed is further spaced for increasing the isolation in between them.

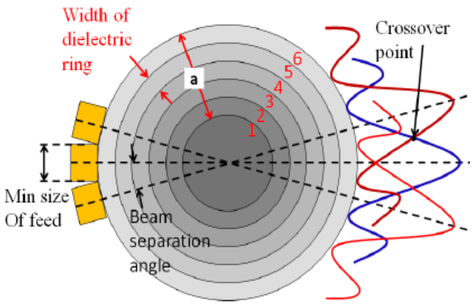

Figure 1: Conceptual design architecture of Luneburg lens for beam optimisation

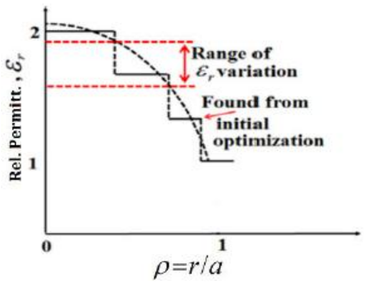

Figure 2: Variation of relative electric permittivity for optimization

we altered the beam overlap with the help of pencil beams. Beam overlap region is decreased when the beam connection is highly stable owing to the uniformly distributed field across the region of main beam. The beam shaping is carried out for optimizing the main beam for superior distribution of the field with minimal overlap. The lens structure parameters deployed for optimizing includes the total size, width of the dielectric rings and its permittivity value. Particularly, the permittivity is relaxed to be greater than two, simultaneously maintaining sequential decrement away from the centre. For assuring the decrement of relative permittivity gradually, we initially select values as in [4], [13] for minimizing the estimated gaps in accordance with (1) as depicted in Fig. 2.

III. PARAMETRIC DESCRIPTION OF LENS OPTIMISATION

The parameters that are considered in the optimisation are thickness of the dielectric ring, dielectric constant value. The initial value set has been determined with the help of optimally chosen discrete parameters of the lens in (1) as given in [4], wherein four rings are taken into consideration involving three dielectric rings and an air.

Table 1: Initial value set of geometric parameters and dielectric values

Indices of shell	1	2	3	4
Thickness in mm	15.8	6.5	5.0	2.2
Dielectric value	1.7	1.4	1.2	1.0

The four scenarios consider combination of variable parameters involving relative permittivity values and the ring's thickness. The varying nature of dielectric value in (1) is made use for discretizing the optimizing range of every ring in Fig. 2. In this scenario, the thickness of every ring stands fixed, as shown in Table 1. Hence, the highest dielectric value in Fig. 2 is two. In addition, second scenario also takes into consideration dielectric value of every ring as the optimizing variable under identical situation. In the optimisation process, we consider the ratio of thickness with respect to fixed lens size. case 1 and case 3 results in the convergence in relative permittivity of approximately two for the centrally located dielectric disk. And in case 2 and case 4 results in an optimum dielectric value above two as expected in an Luneburg lens.

IV. CHARACTERISTICS DISCUSSION

The simulated and the pre-existing measured pattern of radiation is depicted in Fig. 3(a) & (b) respectively, wherein, pattern of nearly uniform fan shape are illustrated under the simulation results as anticipated. A better agreement between the simulations & the pre-existing measured benchmarks has been seen to be achieved with a trivial discrepancy which can be attributed to prototyping discrepancy.

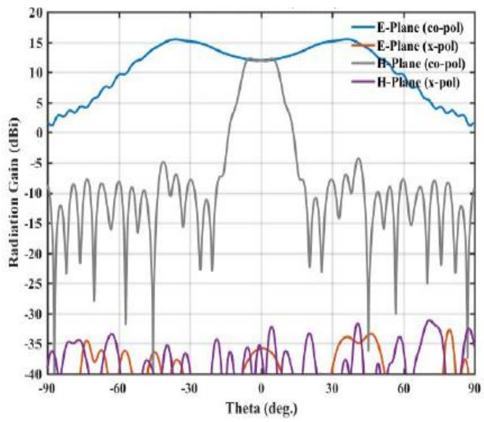

Figure 3(a): Simulated radiation pattern of optimized Lens

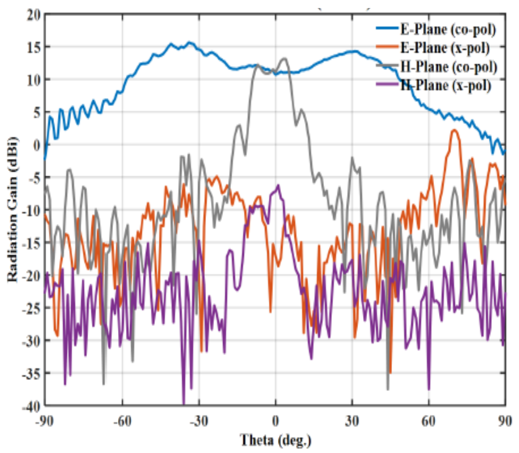

Figure 3(b): Benchmark measurement radiation pattern of optimized Lens

The variation in gain is comparatively uniform across the main beam, wherein the gain value is higher compared to the desired benchmark. The relative cross-polarisation is below -40 dB as achieved from the simulation in Fig. 3(a), which is trivially greater with respect to the measured values owing to the difficult accurate alignments.

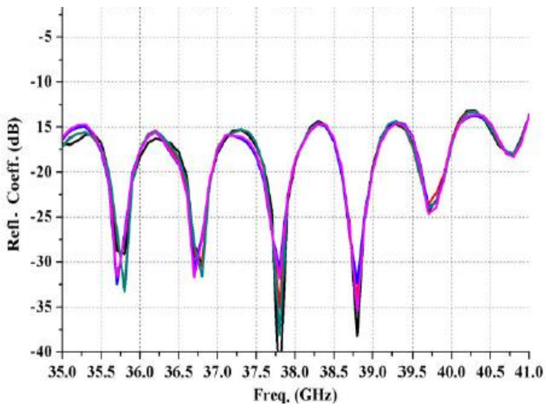

Figure 4(a): coefficients of reflection simulated

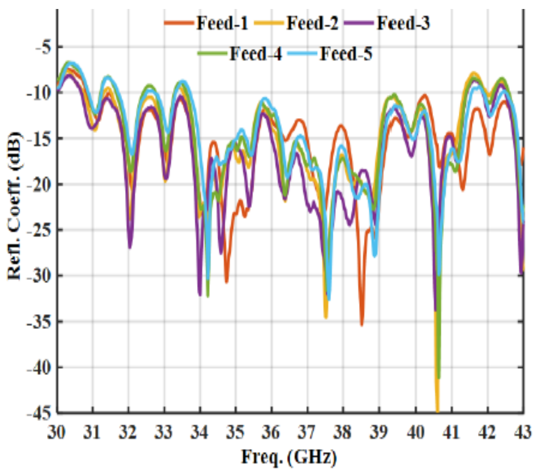

Figure 4(b): coefficients of reflection measured

The simulated and pre-existing benchmark (measures) coefficients of reflection have been depicted in Fig 4(a) & (b) respectively, wherein they exhibit a broader frequency bandwidth. The simulated coefficient of reflection value is less than -15 dB corresponding to majority of frequencies, whereas it is a bit higher in measured result owing to the manufacturing discrepancies and realistic implementations. Overall, there is good agreement of simulation results in general.

V. CONCLUSION

In this work, we presented design for multiple beam radiation accompanied with nearly uniformly distributed pattern for achieving gain stability. Comparison with the existing measured results indicates superior gain in the transitions between successively neighbourhood beams and thereby leading to stable power control. Our comparisons indicate that the gain and coefficient of reflection possess greater stability across the frequency changes.

REFERENCES

[1]. M. Agiwal, A. Roy, and N. Saxena, ''Next generation 5G wireless net- works: A comprehensive survey,'' *IEEE Commun. Surveys Tuts.*, vol. 18, no. 3, pp. 1617–1655, 3rd Quart., 2016.

[2]. A. I. Sulyman, A. T. Nassar, M. K. Samimi, G. R. Maccartney, T. S. Rappaport, and A. Alsanie, ''Radio propagation path loss models for 5G cellular networks in the 28 GHZ and 38 GHZ millimeter-wave bands,'' IEEE Commun. Mag., vol. 52, no. 9, pp. 78–86, Sep. 2014.

[3]. X. Wu and J.-J. Laurin, ''Fan-beam millimeter-wave antenna design based on the cylindrical Luneberg lens,'' *IEEE Trans. Antennas Propag.*, vol. 55, no. 8, pp. 2147–2156, Aug. 2007.

[4]. H.-T. Chou and Z.-D. Yan, ''Parallel-plate Luneburg lens antenna for broadband multi-beam radiation at millimeter wave frequencies with design optimization,'' *IEEE Trans. Antennas Propag.*, vol. 66, no. 11, pp. 5794–5804, Nov. 2018.

[5]. J. Sanford, ''A Luneberg-lens update,'' *IEEE Antennas Propag. Mag.*, vol. 37, no. 1, pp. 76–79, Feb. 1995.

[6]. L. C. Gunderson and G. T. Holmes, ''Microwave Luneburg lens,'' Appl. Opt., vol. 7, no. 5, pp. 801–804, May 1968.

[7]. G. D. M. Peeler and H. P. Coleman, ''Microwave stepped-index Luneburg lenses,'' IRE Trans. Antennas Propag.,vol.6,no.2,pp. 202–207, Apr. 1958.

[8]. Z. Liu and P. Fan, ‘‘An effective handover scheme based on antenna selection in ground–train distributed antenna systems,’’ *IEEE Trans. Veh. Technol.*, vol. 63, no. 7, pp. 3342–3350, Sep. 2014.
[9]. L. Xue and V. F. Fusco, ‘‘Printed holey plate Luneburg lens,’’ Microw. Opt. Technol. Lett., vol. 50, no. 2, pp. 378–380, Dec. 2007.
[10]. L. Xue and V. Fusco, ‘‘Patch-fed planar dielectric slab Luneb urg lens,’’ IET Microw., Antennas Propag., vol. 2, no. 2, pp. 109–114, Mar. 2008.
[11]. C. Hua, X. Wu, N. Yang, and W. Wu, ‘‘Air-filled parallel-plate cylindrical modified Luneberg lens antenna for multiple-beam scanning at millimeter- wave frequencies,’’ *IEEE Trans. Microw. Theory Techn.*, vol. 61, no. 1, pp. 436–443, Jan. 2013.
[12]. G. Godi, R. Sauleau, L. L. Coq, and D. Thouroude, ‘‘Design and optimiza- tion of three-dimensional integrated lens antennas with genetic algorithm,’’ *IEEE Trans. Antennas Propag.*, vol. 55, no. 3, pp. 770–775, Mar. 2007.
[13]. B. Fuchs, L. Le Coq, O. Lafond, S. Rondineau, and M. Himdi, ‘‘Design optimization of multishell Luneburg lenses,’’ *IEEE Trans. Antennas Propag.*, vol. 55, no. 2, pp. 283–289, Feb. 2007.
[14]. H. Mosallaei and Y. Rahmat-Samii, ‘‘Nonuniform Luneburg and two-shell lens antennas: Radiation characteristics and design optimization,’’ *IEEE Trans. Antennas Propag.*, vol. 49, no. 1, pp. 60–69, Jan. 2001.
[15]. B. Fuchs, R. Golubovic, A. K. Skrivervik, and J. R. Mosig, ‘‘Spherical lens antenna designs with particle swarm optimization,’’ *Microw. Opt. Technol. Lett.*, vol. 52, no. 7, pp. 1655–1659, Jul. 2010.
[16]. H.-T. Chou, Y.-S. Chang, H.-J. Huang, Z.-D. Yan, T. Lertwiriyaprapa, and D. Torrungrueng, ‘‘Optimization of three-dimensional multi-shell dielec- tric lens antennas to radiate multiple shaped beams for cellular radiocoverage,’’ *IEEE Access*, vol. 7, pp. 182974–182982, 2019.
[17]. C. S. Silitonga, Y. Sugano, H. Sakura, M. Ohki, and S. Kozaki, ‘‘Optimum variation of the Luneberg lens for electromagnetic scattering calculations,’’ *Int. J. Electron.*, vol. 84, no. 6, pp. 625–633, Jun. 1998.

Deepthi KVBL, et. al. “An Optimized Luneburg Lens Antenna Design for Validating Radiating Gain Stability in Beam Switching.” *International Journal of Engineering Research and Applications (IJERA)*, vol.12 (03), 2022, pp 13-16.