Evaluation of Mutual Coupling in Integrated Lens Array Antennas

Nair, A.; Dabironezare, S.O. ; Neto, A.; Llombart, N.

DOI
10.1109/IRMMW-THz50927.2022.9896096

Publication date
2022

Document Version
Final published version

Published in
Proceedings of the 2022 47th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz)

Citation (APA)
Nair, A., Dabironezare, S. O., Neto, A., & Llombart, N. (2022). Evaluation of Mutual Coupling in Integrated Lens Array Antennas. In *Proceedings of the 2022 47th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz)* (pp. 1-2). IEEE. https://doi.org/10.1109/IRMMW-THz50927.2022.9896096

2022 47th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz) | 978-1-7281-9427-1/22/$31.00 ©2022 IEEE | DOI: 10.1109/IRMMW-THz50927.2022.9896096

Evaluation of Mutual Coupling in Integrated Lens Array Antennas

A.Nair[1], S. O. Dabironezare [1], A. Neto [1] and N. Llombart[1]
[1]THz Sensing Group, Technical University of Delft, The Netherlands

***Abstract*—Future applications in sensing and communications at (sub)-millimetre wavelengths will benefit from having large integrated coherent arrays. The use of lens arrays will enable the fabrication of integrated antenna front-ends with many potential independent beams as well as dynamic scanning capabilities. For applications such as MIMO communications, interferometric arrays and Tx/Rx duplexing capabilities, a key design parameter can be the mutual coupling between the integrated antenna front-ends. In this contribution we model such mutual coupling for lens antenna arrays using Geometrical Optics technique combined with a bidirectional forward ray-tracing. The validation of the methodology against full wave simulations is also presented here.**

I. INTRODUCTION

There is a growing interest in sensing and communications applications at the frequency ranges from 100 GHz to 700 GHz. Applications ranging from space sensing to wide-spread communications networks in this spectral band will highly benefit from employing large integrated antenna arrays. The use of lens arrays facilitates the front-end integration at these high frequencies; therefore these arrays are currently being developed for many such applications [1]-[3]. In these applications, the use of antenna feeds in combination with dielectric lenses is envisaged. A planar antenna placed on a thin high contrast dielectric wafer feeding a dielectric lens can achieve high efficiencies [4], whereas the fabrication of a large array of lenses (>10k pixels) is now possible using commercial machining techniques [5].

The feed isolation requirements in lens array architectures varies between 20dB to 50dB depending on the application [6]-[8]. For example, in emerging applications such as multi-beam Fly's eye antennas for communications [2], the mutual coupling between the different front-ends will impact the signal to noise and interference ratio of the link and therefore the potential capacity of the system. At these high frequencies, low order modulation levels are being proposed [6] leading to mutual coupling level requirements of less than -20dB. As a result, at this moment, the evaluation of the mutual coupling between the integrated antenna front-ends in lens array applications is necessary to assess the potential of such arrays.

II. GO MODELING AND VALIDATION

Previous works [9] - [10] have studied the effect of multiple reflections in the input impedance and the mutual coupling of antennas below a single lens. In this contribution, we extend these works to investigate the level of mutual coupling in lens array configurations. To achieve this goal, we have developed a numerical technique based on Geometrical Optics (GO) combined with bi-directional forward raytracing [11], see Fig.1 that shows fair agreement with full wave simulations while being numerically efficient. The mutual coupling in these geometries has two main contributors: the direct spherical wave radiating from the source referred here as the direct coupling and the lens reflection contributions referred as the lens coupling. Using this model, the main causes of mutual coupling in a lens array configuration is investigated.

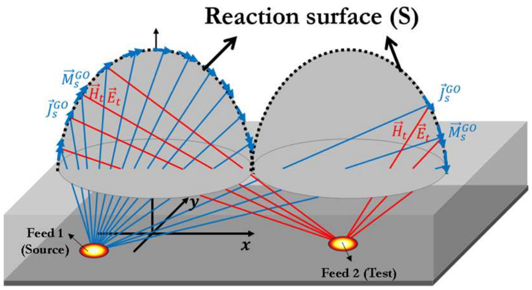
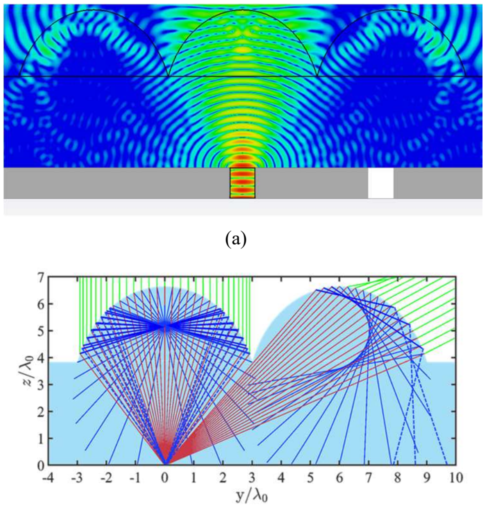


Fig. 1. Evaluation of lens coupling using bi-directional forward ray tracing. Feed 1 (source) is the radiating source in the presence of the lens array. Feed 2 (test), is displaced along the focal plane of the lens array and receives the scattered fields of the source feed.

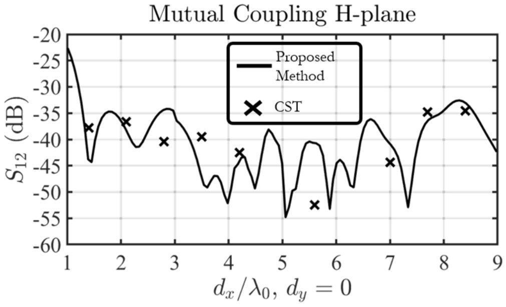
The mutual coupling achieved using the proposed model is also compared to that of a CST-MS full wave simulation for validation purposes. Here, the mutual coupling between the source feed and the test feed, as shown in Fig. 1, is evaluated as a function of the test feed displacement. For this validation, we consider a plastic lens array scenario with a relative permittivity of $\epsilon_r = 2.5$, focal length to diameter (f-number) of $f_\# = 0.81$, and lens diameters of $D_{lens} = 6\lambda_0$, where λ_0 is the wavelength in free space. The central lens is fed by a circular waveguide (CWG) with diameter of $D_f = 1.6\lambda_d$, where λ_d is the wavelength in the plastic dielectric. The 2-D representation of electric fields over the lens array from CST-MS is shown in Fig. 2. (a) along with the ray-tracing figure of the same geometry analyzed by the proposed method in Fig. 2 (b). A second similar



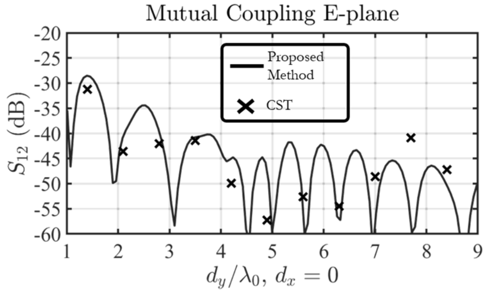
(b)

Fig. 2. (a) A 2-D representation of electric fields illuminated by a CWG feed in the plastic lens array from full wave simulation in CST, and (b) the corresponding ray-tracing picture by the proposed method where the red, blue, and green lines represent the incident, reflected and transmitted rays.

CWG, acting as the test feed, is displaced along the main planes of the lens array. The mutual coupling in terms of scattering parameter S_{12} as a function of the displaced test feed location is computed. The mutual coupling obtained using the model is compared with the one of the CST as shown in Fig. 3(a) and (b) for plastic lens array with feeds displaced in H- and E-plane, respectively. The proposed model achieved an excellent agreement with full wave simulations in both planes considering the fact that only the first and second reflections on the lens arrays are included in the model.



(a)



(b)

Fig. 3. Mutual coupling as a function of test feed displacements in (a) H-plane and (b) E-plane.

The average time elapsed to compute the mutual coupling per test location in CST for this plastic lens array, with relatively small lens diameters, is 42 minutes. The simulations are performed in a standard workstation computer. On the other hand, the proposed model provides comparable results to the one of the full wave simulation within 3.2 minutes in the same computer.

III. CONCLUSION

In this work, we have presented a numerical GO method combined with bidirectional ray tracing to evaluate the mutual coupling in lens antenna arrays. In this model, the mutual coupling is approximated by three main contributions: space wave propagating within the lens dielectric, primary and secondary reflections accruing on the lens array surface. The methodology is compared against full wave simulations for a plastic lens array fed by circular waveguides. The obtained results are in excellent agreement with the ones of full wave simulation while being more than 10 times faster to generate. Due to the numerical efficiency of the proposed method, it can be used to perform parametric analysis on the lens arrays in order to understand its impact on the mutual coupling. A more complete study comparing several lens array parameters will be presented in the conference.

REFERENCES

[1] H. Zhang, S. Bosma, A. Neto, and N. Llombart, "A dual-polarized 27dbi scanning lens phased array antenna for 5g point-to-point communications," *IEEE TAP*, vol. 69, no. 9, pp. 5640-5652, 2021.

[2] M. Arias Campo, D. Blanco, S. Bruni, A. Neto, and N. Llombart, "On the use of fly's eye lenses with leakywave feeds for wideband communications," *IEEE TAP*, vol. 68, no. 4, pp. 2480–2493, 2020.

[3] M. Alonso-delPino, S. Bosma, C. Jung-Kubiak, G. Chattopadhyay, and N. Llombart, "Wideband multimode leaky-wave feed for scanning lens-phased array at submillimeter wavelengths," *IEEE TTST*, vol. 11, no. 2, pp. 205–217, 2021.

[4] D. Filipovic, et al., "Double-Slot Antennas on Extended Hemispherical and Elliptical Silicon Dielectric Lenses", *IEEE TMTT*, Oct. 1993.

[5] J. J. A Baselmans, et al., "A kilo-pixel imaging system for future space based far-infrared observatories using microwave kinetic inductance detectors," *ArXiv e-prints*, Sept. 2016.

[6] N. Llombart, D. Emer, M. Arias Campo, and E. McCune, "Fly's eye spherical antenna system for future tbps wireless communications," *EuCAP*, 2017.

[7] V. Kangas, *et al.*, "Metop Second Generation Microwave Sounding and Microwave Imaging Missions", *EUMETSAT* 2012.

[8] J. Christensen, *et al.*, "GAS: Geostationary Atmospheric Sounder", *IGARSS* 2007.

[9] A. Neto, S. Maci, and P. de Maagt, "Reflections inside an elliptical dielectric lens antenna," IEE Proceedings-Microwaves, Antennas and Propagation, vol. 145, no. 3, pp. 243–247, 1998.

[10] A. Neto, D. Pasqualini, A. Toccafondi, and S. Maci, "Mutual coupling between slots printed at the back of elliptical dielectric lenses," *IEEE TAP*, vol. 47, no. 10, pp. 1504–1507, 1999.

[11] M. M. Taygur and T. F. Eibert, "A ray-tracing algorithm based on the computation of (exact) ray paths with bidirectional ray-tracing," *IEEE TAP*, vol. 68, no. 8, pp. 6277–6286, 2020.