# Closed-Form Homogenization of Glide-Symmetric Metasurfaces

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**Summary**

This abstract presents a new analytic homogenization technique for glide-symmetric holey parallel plate waveguides. The dispersion equation of these structures is formulated by means of a mode-matching, and is further simplified at low frequency ny using the properties of the modes resonating within each holes. The simplified equation yields a closed-form expression of the effective refractive index valid for arbitrarily shaped holes, which is successfully validated with commercial solvers. The expression is over an ultra-wide band, due to the low dispersive properties of glide symmetric structures. It is then used to compute suitably defined electromagnetic parameters of the waveguide thus showing the fundamental difference between a non-glide and glide structure.

## 1 Introduction

Modern wireless communication systems must meet the needs of increasingly many connected users and devices [1], which require high data rates easily available at millimeter waves and beyond. Phased arrays at these frequencies are bulky, very power consuming, and very expensive which motivates the use of near-optical solutions such as lens antennas [2]. Compact and conformable designs can be obtained with planar lenses, but they have limited performances due to losses related to dielectric materials. An alternative is to build integrated lenses using planar waveguides made of metasurfaces; unfortunately metasurfaces tend to be narrowband due to their inherent frequency dispersion.

In recent years, it has been shown that the dispersive behavior and the refractive index range of such PPW can be improved using glide symmetry (GS). GS is a special type of higher symmetry, where the geometry of the waveguide is invariant after a translation of half-a-unit-cell and a reflection with respect to a plane (Fig. 1(a)). Not only has this added symmetry been shown to enhance the refractive index of the all-metallic waveguide, but also the dispersive behavior of the structure is mitigated, due to the disappearance of the bandgap between the first and second propagating modes. GS also offers a higher anisotropic behavior than non-glide designs, leading to wideband lenses compressed with transformation optics [3]. Wideband lowloss lenses have been designed using various metasurface unit cells [4], [5]. Nevertheless, these designs rely on cumbersome parametric studies: the interesting features of GS PPWs reach their full potential when the gap between the two metasurfaces is very small compared to the other characteristic dimensions of the unit cell, which makes numerical commercial solvers prohibitively slow.

## 2 Multimodal transfer-matrix method

In this abstract, we propose a homogenization technique capable to avoid the numerical solutions of full-wave problems, since it gives a closed-form solution of the effective refractive index of a holey GS PPW. We derive the dispersion equation by means of the Mode-Matching Method presented in [44], and we simplify this dispersion equation at low frequencies. The simplified equations has a closed-form solution for the effective refractive index. Due to the low dispersive behavior of the waveguide, this low-frequency index is valid over a large frequency band.

For the sake of brevity the final formula is not shown here, and can be found with all the necessary mathematical details in [6]. In Fig. 1(b) we use this formula for holey GS PPWs with rectangular holes, in order to study the propagation of waves along an arbitrary direction forming the angle $\theta$ with one of the hole sides (as shown in the inset). The result is compared with a low-frequency solution of the CST Microwave Studio eigensolver, showing a perfect agreement. The closed-formula result has been obtained without solving a full-wave problem, thus leading to a significant computational speed up, particularly interesting for parametric analyses and optimization problems. Further studied led to the computation of equivalent electromagnetic parameters (effective dielectric and magnetic constants) describing the different electromagnetic behaviour of glide and non-glide waveguides. More details, examples and applications will be shown at the conference.

## 3 Acknowledgements

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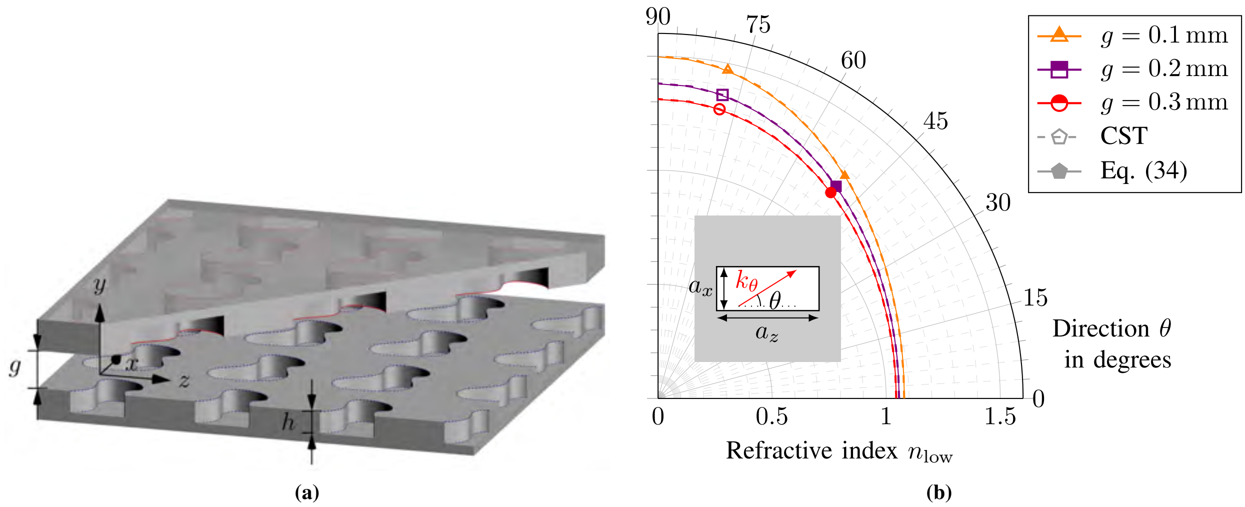


**Figure 1.** (a) Example of two-dimensional GS holey metasurface supporting the propagation of a wave between the metallic plates. (b) Refractive index of a holey GS with holes of rectangular shape (see inset) for different propagation directions $\theta$.

## References


[1] L. Kong, M. K. Khan, F. Wu, G. Chen, and P. Zeng, "Millimeter-wave wireless communications for iot-cloud supported autonomous vehicles: Overview, design, and challenges," *IEEE Communications Magazine*, vol. 55, no. 1, pp. 62–68, 2017.

[2] O. Quevedo-Teruel, M. Ebrahimpouri, and F. Ghasemifard, "Lens antennas for 5g communications systems," *IEEE Communications Magazine*, vol. 56, no. 7, pp. 36–41, 2018.

[3] O. Quevedo-Teruel, Q. Chen, F. Mesa, N. J. G. Fonseca, and G. Valerio, "On the benefits of glide symmetries for microwave devices," *IEEE Journal of Microwaves*, vol. 1, no. 1, pp. 457–469, 2021.

[4] W. Yuan, J. F. Chen, C. Zhang, W. X. Tang, L. Wang, Q. Cheng, and T. J. Cui, "Glide-symmetric lens antenna in gap waveguide technology," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 4, pp. 2612–2620, 2020.

[5] Q. Chen, F. Giusti, G. Valerio, F. Mesa, and O. Quevedo-Teruel, "Anisotropic glide-symmetric substrate-integrated-holey metasurface for a compressed ultrawideband luneburg lens," *Applied Physics Letters*, vol. 118, no. 8, p. 084102, 2021.

[6] B. Fischer and G. Valerio, "Quasi-static homogenization of glide-symmetric holey parallel-plate waveguides with ultra-wideband validity," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 11, pp. 10569–10582, 2022.