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XXXVII Cycle

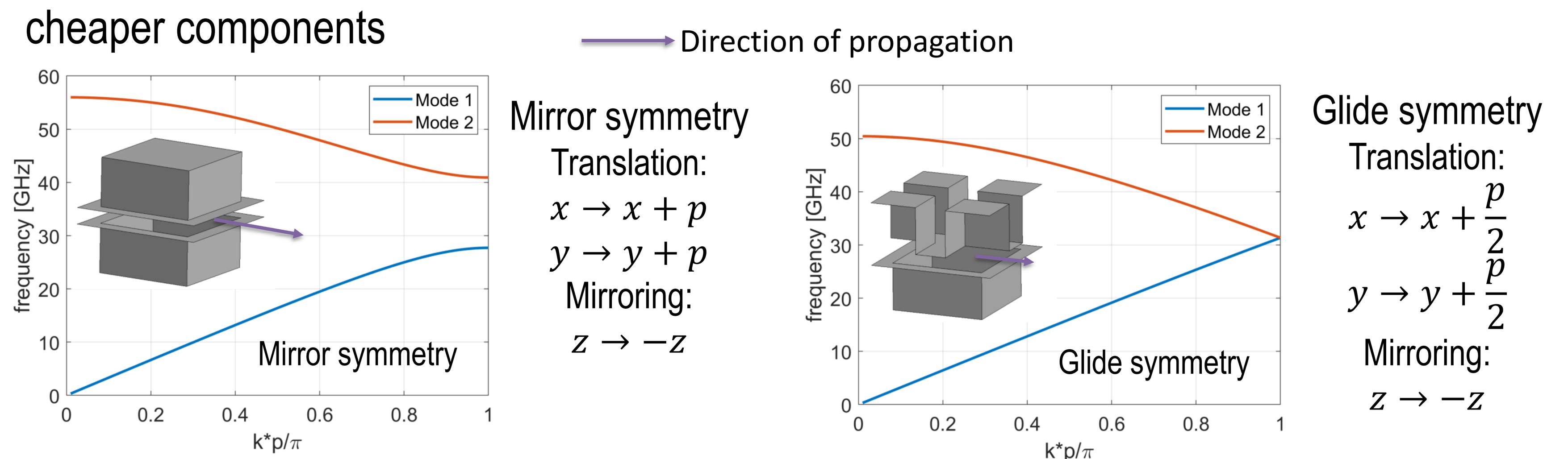
Future communications with glide-symmetric engineered artificial materials

Martin Petek

Supervisors: Prof. Francesca Vipiana, Assist. Prof. Jorge Alberto Tobon Vasquez, Prof. Oscar Quevedo-Teruel

Research context and motivation

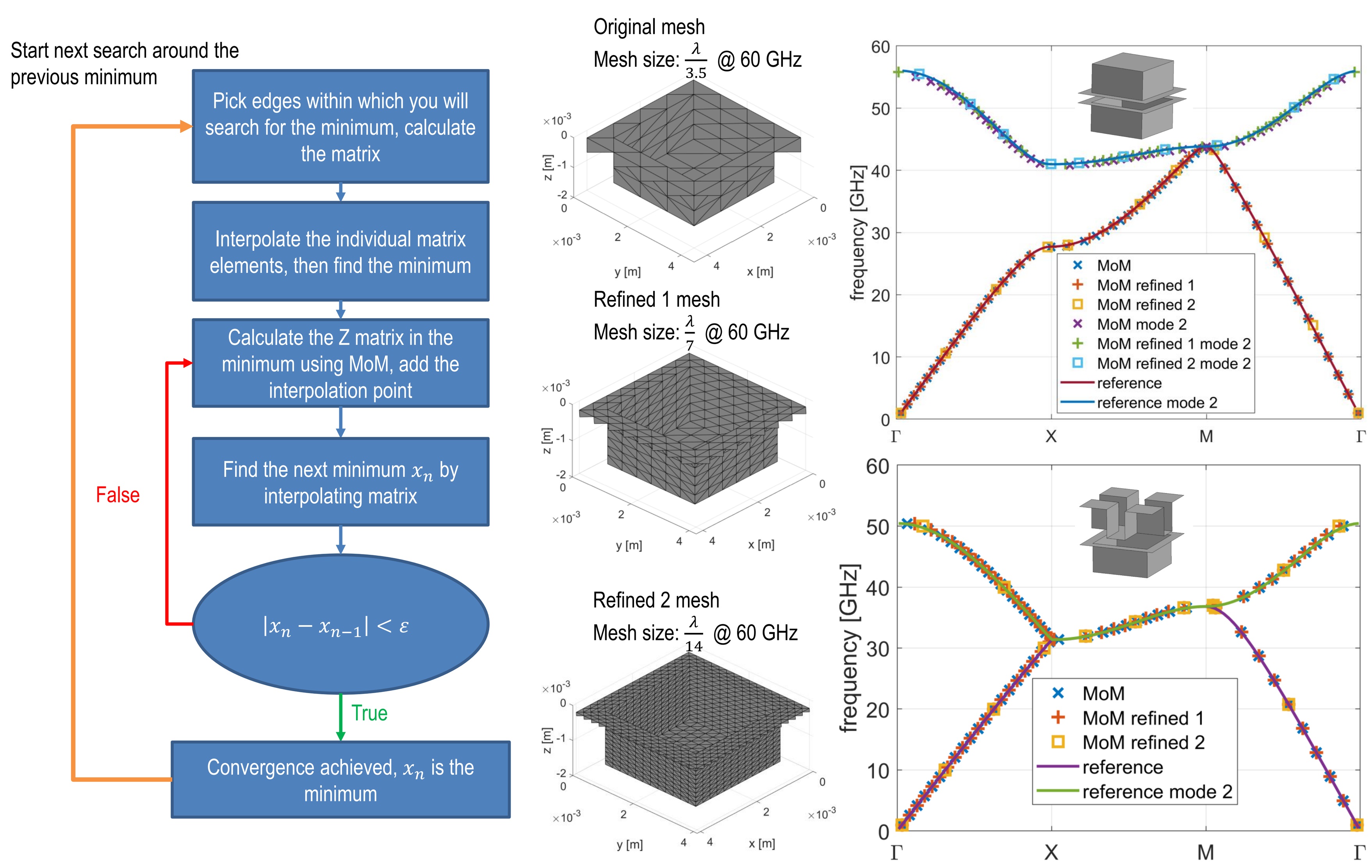
- Telecommunication systems are moving to higher frequencies, requiring more efficient antennas and antenna components
- Recently, periodic structures have gained a lot of attention due to their ability to tailor propagation of the waves and the ability to create highly efficient fully-metallic structures
- Introducing higher symmetries in periodic structures changes how electromagnetic waves propagate, which can be exploited in designing RF components
- A commonly explored higher symmetry is glide symmetry, which is obtained by mirroring the bottom part and then shifting it half a period
- Using glide symmetry, the first stopband is closed, which reduces dispersion and thus allows for a wide band of operation. Alternatively, the size of the unit cell can be increased, which reduces required manufacturing tolerances and helps in creating more robust and cheaper components



- There is a need for custom codes, as currently available commercial codes can't compute complex eigenvalues or the attenuation in the stopband

Addressed research questions/problems

- One of key problems addressed was accurate computation of the integrals. Since the structure is periodic and symmetric, there are many singularities present which need to be properly treated for accurate integration.
- We developed zero-search algorithms to find all modes within a certain frequency range. The method starts by computing impedance matrix for a set number of frequencies obtaining approximation of others via interpolation. Then, the matrix is computed for the values of parameters where it is singular and added to the interpolation scheme. This procedure is repeated until all singular frequencies fall within a tolerance range.
- We have extensively verified the code for different mesh sizes and shown that our numerical scheme is converging.



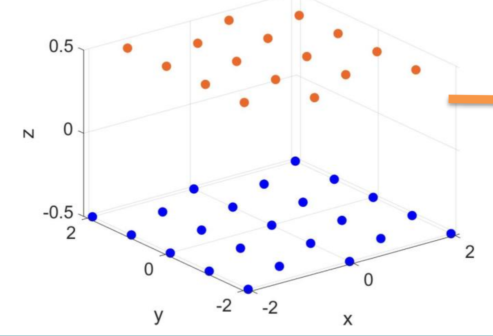
Submitted and published works

- N/A

Novel contributions

- We developed a novel Green's function which facilitates design of glide-symmetric structures, allowing us to only simulate the bottom part of the unit cell
- The Green's function consists of two periodic Green's functions, which are summed or subtracted depending if the mode can be mirrored with a perfect electric conductor (PEC) or perfect magnetic conductor
- The phase shift in the structure is accounted for by introducing $e^{-j\boldsymbol{k}_{t00}\cdot(b_1 s_1 + b_2 s_2)}$ and the distance is updated to $R_{mn,t}$

$$G(\boldsymbol{r}, \boldsymbol{r}') = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} G_{m,n} \pm G_{m,n,t}$$



$$G_{m,n,t} = e^{-j\boldsymbol{k}_{t00}\cdot(b_1 s_1 + b_2 s_2)} e^{-j\boldsymbol{k}_{t00}\cdot\boldsymbol{\rho}_{mn}} \frac{e^{-jkR_{mn,t}}}{4\pi R_{mn,t}}$$

$$G_{m,n} = e^{-j\boldsymbol{k}_{t00}\cdot\boldsymbol{\rho}_{mn}} \frac{e^{-jkR_{mn}}}{4\pi R_{mn}}$$

Adopted methodologies

- We describe the conductive surface S as the perfect electric conductor (PEC) and obtain the electric field integral equation (EFIE)
- The infinite periodicity of the structure is included in the Green's function
- The analyzed surface is discretized into triangles and the current in the EFIE is expanded into Rao-Wilton-Glisson basis functions
- Triangles are added to the edge to ensure electric connection between adjacent unit cells
- A system of equations is obtained with a Galerkin testing procedure
- The excitation vector is set to zero, as we are searching for modes in the structure
- The system has a solution when the determinant is exactly zero (the matrix is singular)
- Due to finite precision of computations, we search for points where the matrix has a high condition number compared to nearby regions

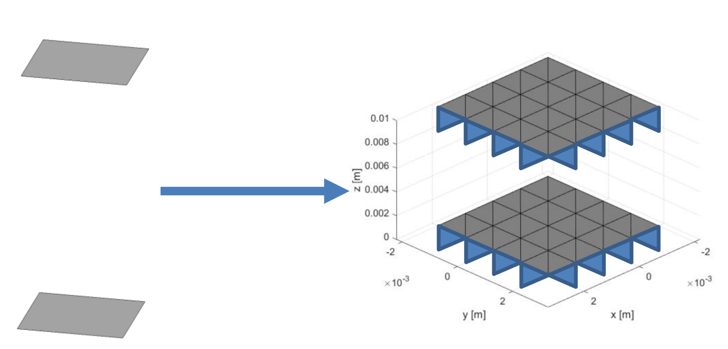
$$\boldsymbol{E}^S = -j\omega\mu \int_S \boldsymbol{J}(\boldsymbol{r}') G(\boldsymbol{r}, \boldsymbol{r}')\, dS' + \nabla \frac{1}{j\omega\varepsilon} \int_S \nabla' \cdot \boldsymbol{J}(\boldsymbol{r}') G(\boldsymbol{r}, \boldsymbol{r}')\, dS'$$

$$\boldsymbol{J}(\boldsymbol{r}) = \sum_{n=1}^{N} I_n \boldsymbol{\Lambda}_n(\boldsymbol{r}), \quad \boldsymbol{r} \in S$$

$$[Z_{mn}] = j\omega [L_{mn}] + \frac{1}{j\omega} [S_{mn}]$$

$$L_{mn} = \mu \int_S dS \boldsymbol{\Lambda}_m(\boldsymbol{r}) \cdot \int_S dS' \boldsymbol{\Lambda}_n(\boldsymbol{r}') G(\boldsymbol{r}, \boldsymbol{r}')$$

$$S_{mn} = \frac{1}{\varepsilon} \int_S dS\, \nabla \cdot \boldsymbol{\Lambda}_m(\boldsymbol{r}) \int_S dS' \nabla' \cdot \boldsymbol{\Lambda}_n(\boldsymbol{r}') G(\boldsymbol{r}, \boldsymbol{r}')$$



$$\boldsymbol{Z}(\boldsymbol{k}_{t00}) \boldsymbol{I} = \boldsymbol{0} \;\rightarrow \det(\boldsymbol{Z}(\boldsymbol{k}_{t00})) = 0$$

Future work

- Increasing the speed of computation of the matrix further, either by accounting for internal symmetries in the structure or by parallelizing the code (or both)
- Extending the formulation to 1D-periodic 2D structures and 1D-periodic 3D structures and to planar PCB structures
- Introducing a model of lossy metals to obtain complex eigenvalues
- Introducing a MoM formulation where dielectrics could be included in the simulation
- Improving the zero-search algorithm to accelerate the search

List of attended classes

- 01DPJRV – Lens antennas: Fundamentals and present applications. (7/12/2021, 2)
- 01NDLRV – Lingua italiana I livello (17/2/2022, 3)
- 01SFVRV – Metamaterials: Theory and multiphysics applications (8/4/2022, 4)
- 01UIZRV – Microwave sensing and imaging for innovative applications in health and food industry (22/3/2022, 4)
- 01RGBRV – Optimization methods for engineering problems (7/6/2022, 6)
- 01MNFIU – Parallel and distributed computing (21/7/2022, 5)
- N/A – ESoA Course: Metalenses for Antenna Applications (30/4/2022, 3)

Politecnico di Torino

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PhD program in
Electrical, Electronics and Communications Engineering