Odyssey Research Programme
School of Physical and Mathematical Sciences

Machine optimization of radiative grating (Smith-Purcell Radiation)

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Smith-Purcell Radiation

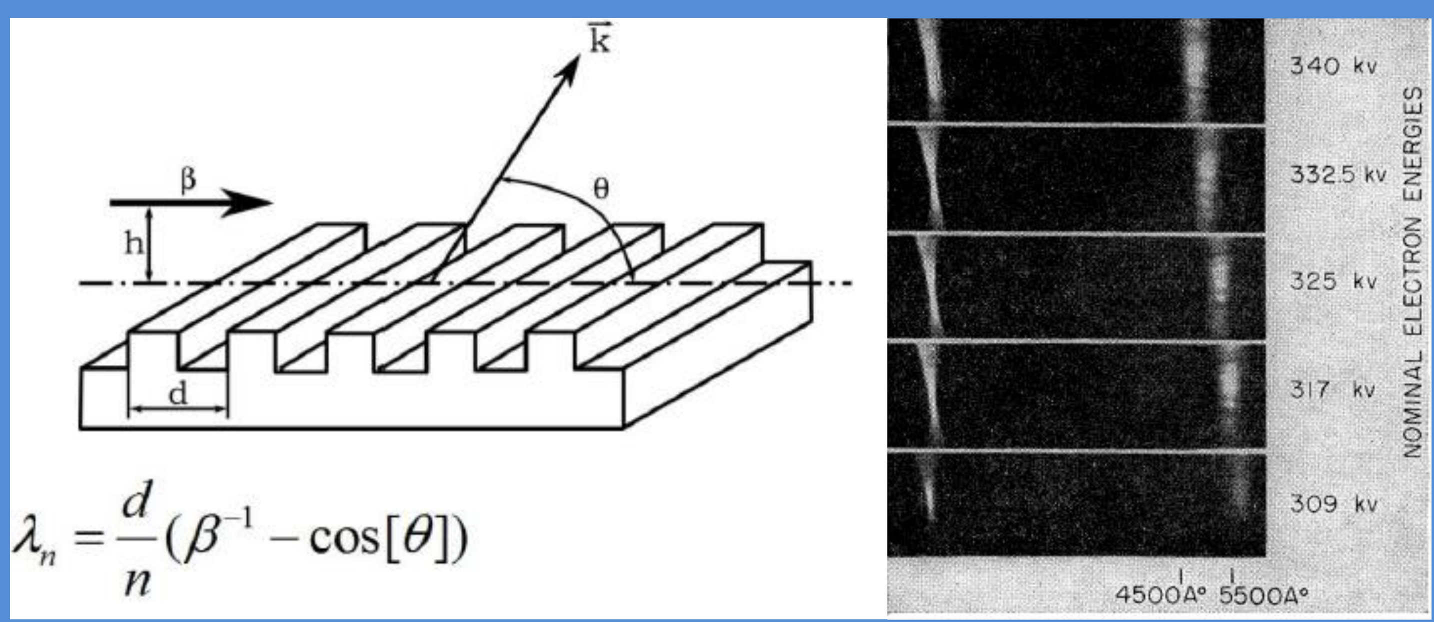

Figure 1, (left) shows a simple model for the Smith-Purcell Radiation and the formula used to derive the wavelength produced given the speed of the electrons, angle measured, and periodicity of the grating. (right) shows the experimental results from the first SPR experiment [1].

In 1953, Steve Smith under Edward Purcell experimented with electron beams travelling parallel and close to a periodic grating and demonstrated that it is a viable way to generate visible light [1].

Unlike Cherenkov radiation, there is not threshold velocity for the generation of SPR [1]. This have become a point of interest as a viable way of producing intense monochromatic light without the limitations found in LASERs.

Adjoint Optimisation in action

Electromagnetic (EM) based designs faces challenges due to the high computational cost to get accurate results, leading to simpler unsupervised methods unviable [4].

The adjoint-based optimisation provides a computationally cheap method for optimising EM-based devices. By exploiting the, linearity of Maxwell's equation and linear medias, the effect of adding/removing dielectric materials from the simulation cell can be calculated quickly [5].

The program can then maximise or minimise the transmission to the objective as per user definition [5].

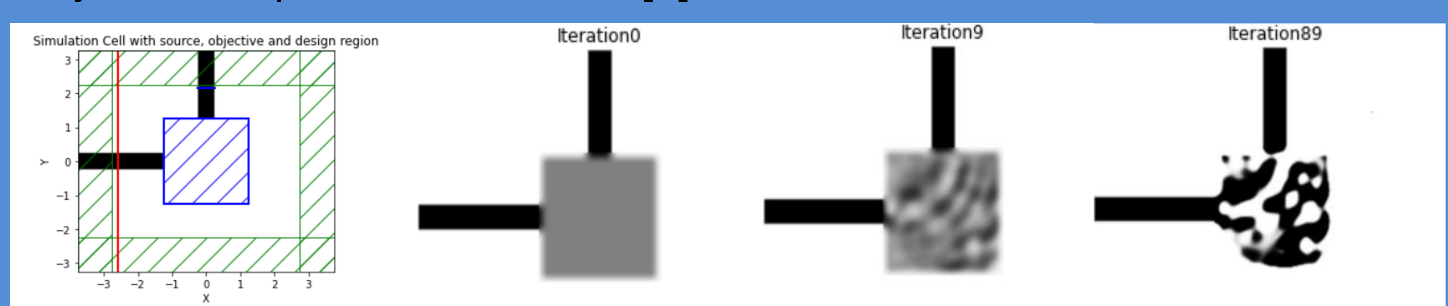

Figure 3 shows the adjoint optimisation process. On the left, the simulation cell with source [red], design region [blue box] and objective [blue line]. Next shows the 'guess' solution, and the progression of the optimisation.

A common way of calculating how well an iteration is performing is by calculating a Figure of Merit (FoM) using the user defined objective function [6].

In the given example, the FoM is calculated by the squared intensity of the electric field (in Z axis). However, the FoM can be arbitrarily defined.

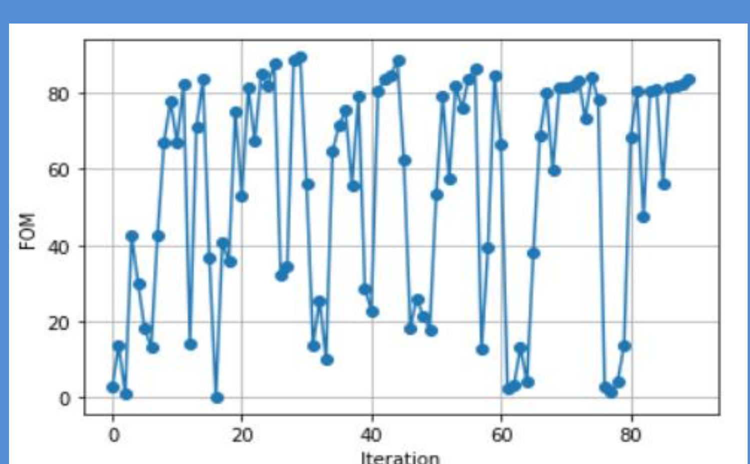

Figure 4 the evolution of the figure of merit with the number of iteration

MEEP and MPA

MEEP is a free and open-source software package for electromagnetics simulation via the finite-difference time-domain (FDTD) method [2].

A time-domain electromagnetic simulation uses Maxwell's equations over time using finite computational volume acting as a form of numerical experiment [2].

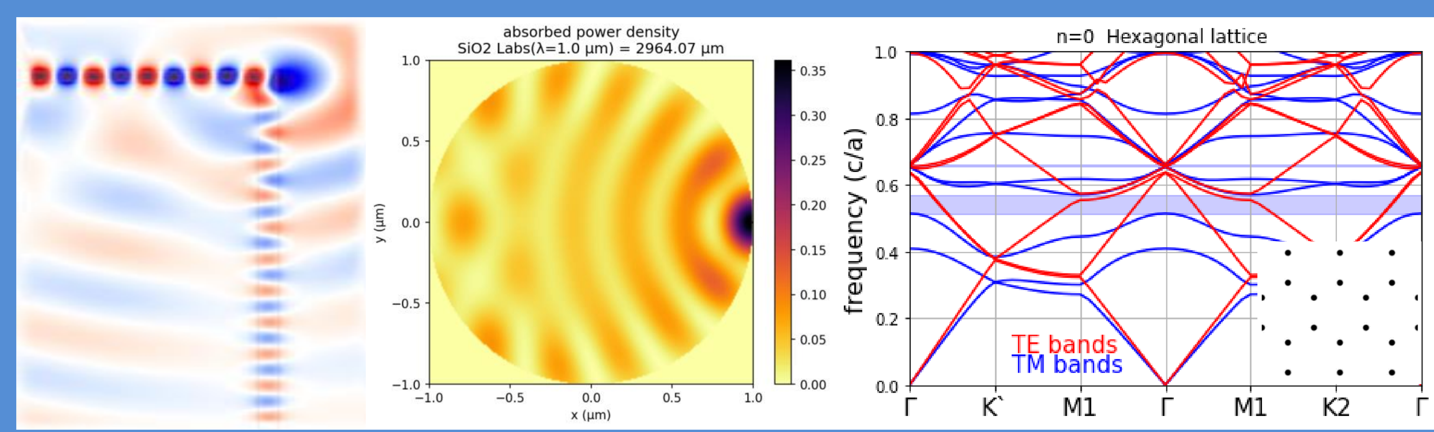

Figure 2 shows a few example of the experiments that MEEP can perform.
(left) Transmission of light through a waveguide with 90-degree bend [3] (middle) Mie scattering [3] (right) Calculation of photonic bands given a unit cell.

Smith Purcell radiation in MEEP

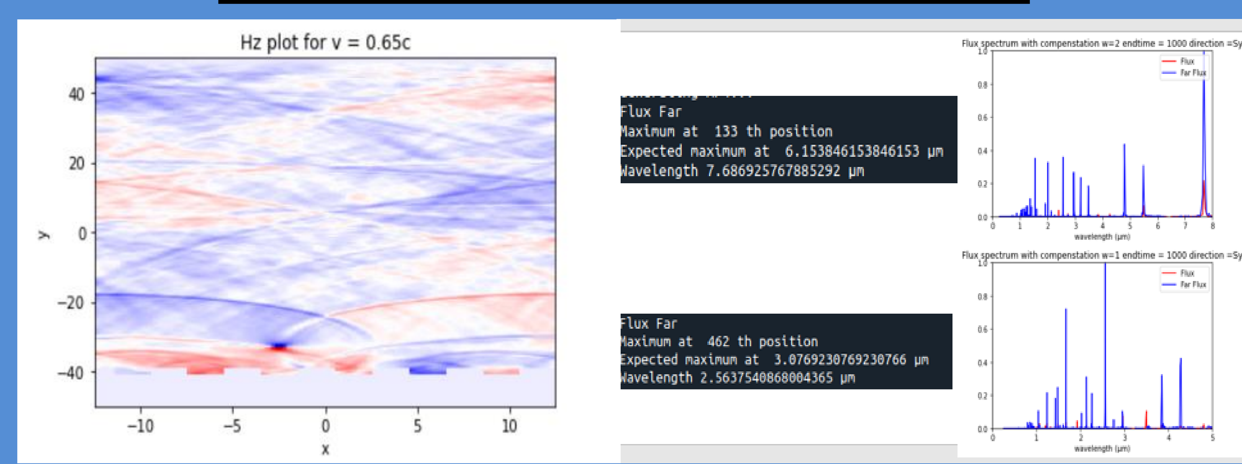

Figure 5 shows the Smith-Purcell experiment ran in MEEP. (left) shows the field configuration at the end of the simulation [t=400μs] (right) shows the measurement of Poynting flux over the entire period, normalised.

The Smith-Purcell experiment can be perform using the MEEP package as demonstrated above. The wavelength emitted by the grating closely matches that which is expected.

However, due to the limitation of computational power, a small finite grating is used which might have caused the discrepancies seen.

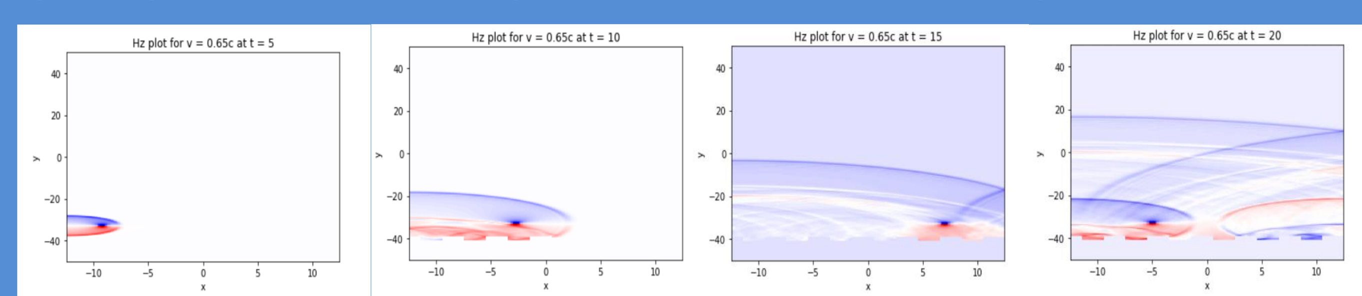

Figure 6 shows snapshots of the simulation at different points of time, increments of 5 μs. After the electron pass right end of the cell, it returns to the left end of the cell.

Conclusion

The adjoint solver method of optimisation is an efficient and effective way to optimise electromagnetic simulations. We have not seen any reasons to believe that the adjoint method cannot be used to optimise the Smith Purcell Radiation devices.

References :

[1] S. J. S. A. E. M. PURCELL, "Visible Light from Localized Surface Charges Moving across a Grating," 1953.
[2] MEEP, "MEEP Manual," [Online]. Available: https://meep.readthedocs.io/en/latest/.
[3] MEEP, "Python Tutorial (Basics)," [Online]. Available: https://meep.readthedocs.io/en/latest/Python_Tutorials/Basics/.
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[6] MEEP, "Fourier Fields Optimization in Waveguide Bend," [Online]. Available: https://github.com/NanoComp/meep/blob/master/python/examples/adjoint_optimization/Fourier%20Fields%20Optimization%20in%20Waveguide%20Bend.ipynb.