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Design Optimization of a Multi-Resonant Piezoelectric Energy Harvester

Siyang Hu, Arwed Schütz, Dennis Hohlfeld, Tamara Bechtold

Introduction

The deployment of Industry 4.0 requires a significant amount of sensors for maintenance and failure prevention. These sensors must often be deployed wirelessly and in harsh environments. Nevertheless, their permanent availability has to be guaranteed for a long period of time. These and additional spatial restrictions eliminate the usability of conventional power supply. One viable approach is harvesting environmental energy present in close proximity of the sensors, such as sunlight, heat or vibrations. In this project, we use a mathematical two-step optimization approach to identify optimal geometrical designs for a tunable multi-resonant piezoelectric energy harvester (PEH), which harvests mechanical vibration energy and transforms it into electrical power via the piezoelectric effect. Multi-resonance and tunability make the PEH more robust to varying environmental excitation frequency caused by e.g. temperature change or humidity.

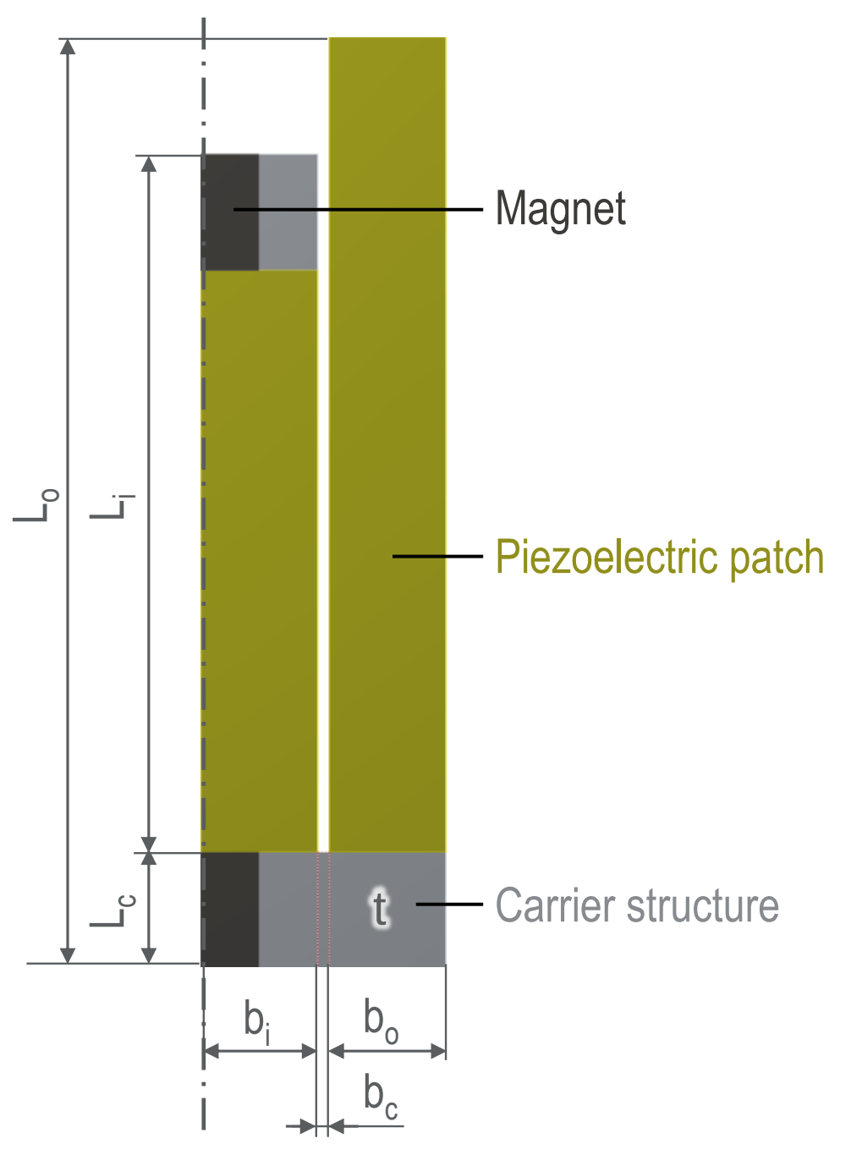
Design Goals

1. Minimize gap between the first two resonance frequencies (Δf_{rel})
2. Set the mean resonance frequency at 75 Hz (f)
3. Maximize power density (PD)
4. Minimize difference in power output at the first two resonance frequencies (P Ratio)

Parametrization and Design Domain

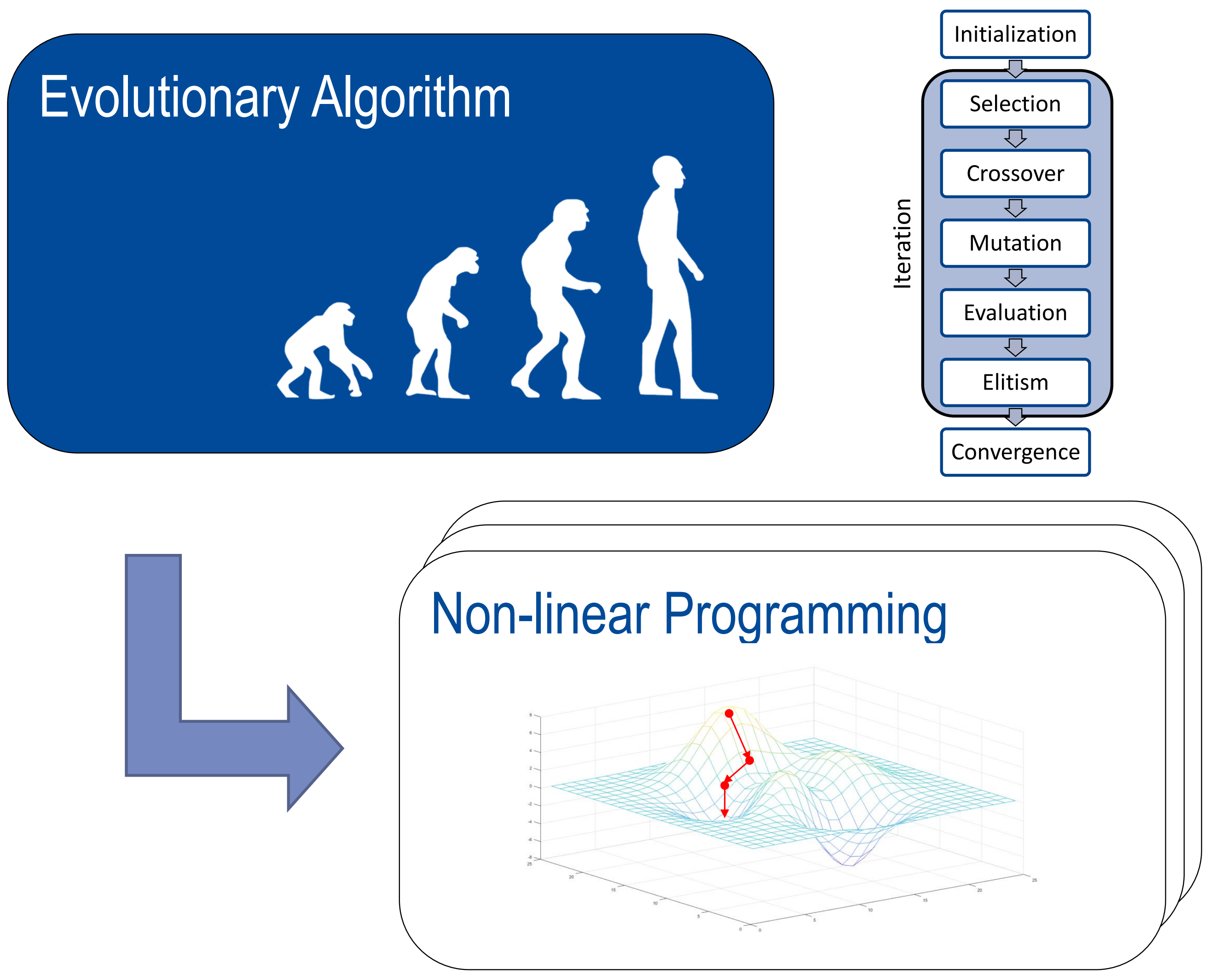
Parameter	Lower Bound	Upper Bound
L_o [mm]	40	120
b_o [mm]	5	15
L_c [mm]	5	15
b_c [mm]	0.5	1.5
L_i [mm]	23	113
b_i [mm]	5	15
t^1 [mm]	0.5	1.5
m_1	Set constant, because these parameters originate from magnets, which have fixed mass and position for optimal frequency tuning properties.	
m_2		
L_{m1}		
L_{m2}		

[1] discrete parameter due to its manufacturing process



Two-Step Optimization

1. Global Optimization
    - Multi-objective
    - Samples the whole design space and identifies interesting subspaces
2. Local Optimization
    - Single-objective
    - Finds the optimal design in each of the interesting subspaces



Evolutionary Algorithm

Initialization
Selection
Crossover
Mutation
Evaluation
Elitism
Convergence

Non-linear Programming

Results

We initialize the global optimization with a starting population of 3500 individuals, which are optimally distributed over the whole design space using Monte Carlo sampling. The evolutionary algorithm results in 2500 Pareto optimal designs, which are shown in Figure 1.

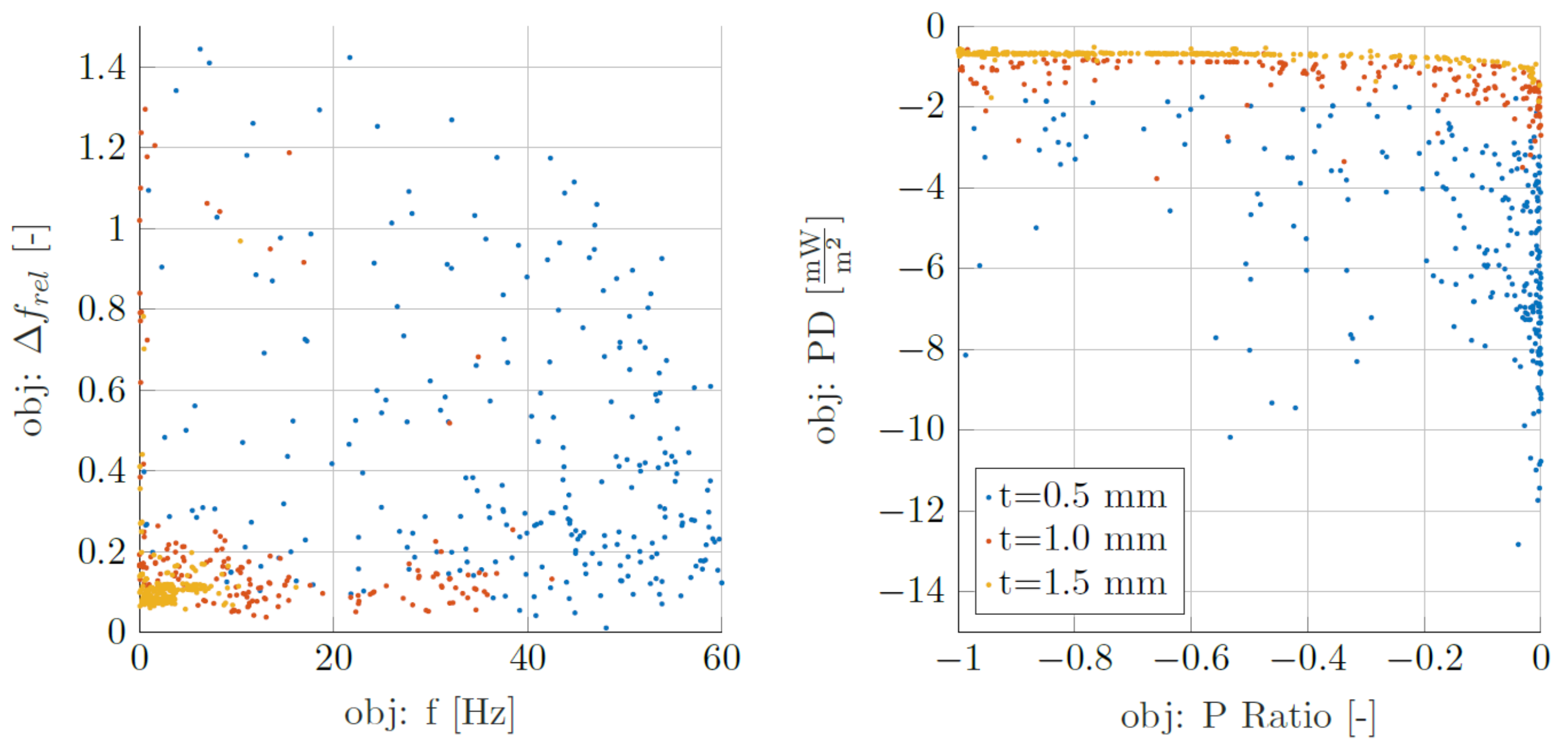


Figure 1: The Pareto frontier generated by the evolutionary algorithm.

Designs that excel in three of four objectives are chosen for the subsequent local, single objective optimization, in order to improve the remaining objective value. We performed the whole optimization process for two different type of piezoelectric patches: the standard PZT patches and macro fiber composite (MFC) patches, which are encapsulated in epoxy. The optimized geometries and respective power density plots for both type of patches with different thicknesses of the carrier structure are depicted in Figure 2. Optimization was performed with ANSYS/optiSLang.

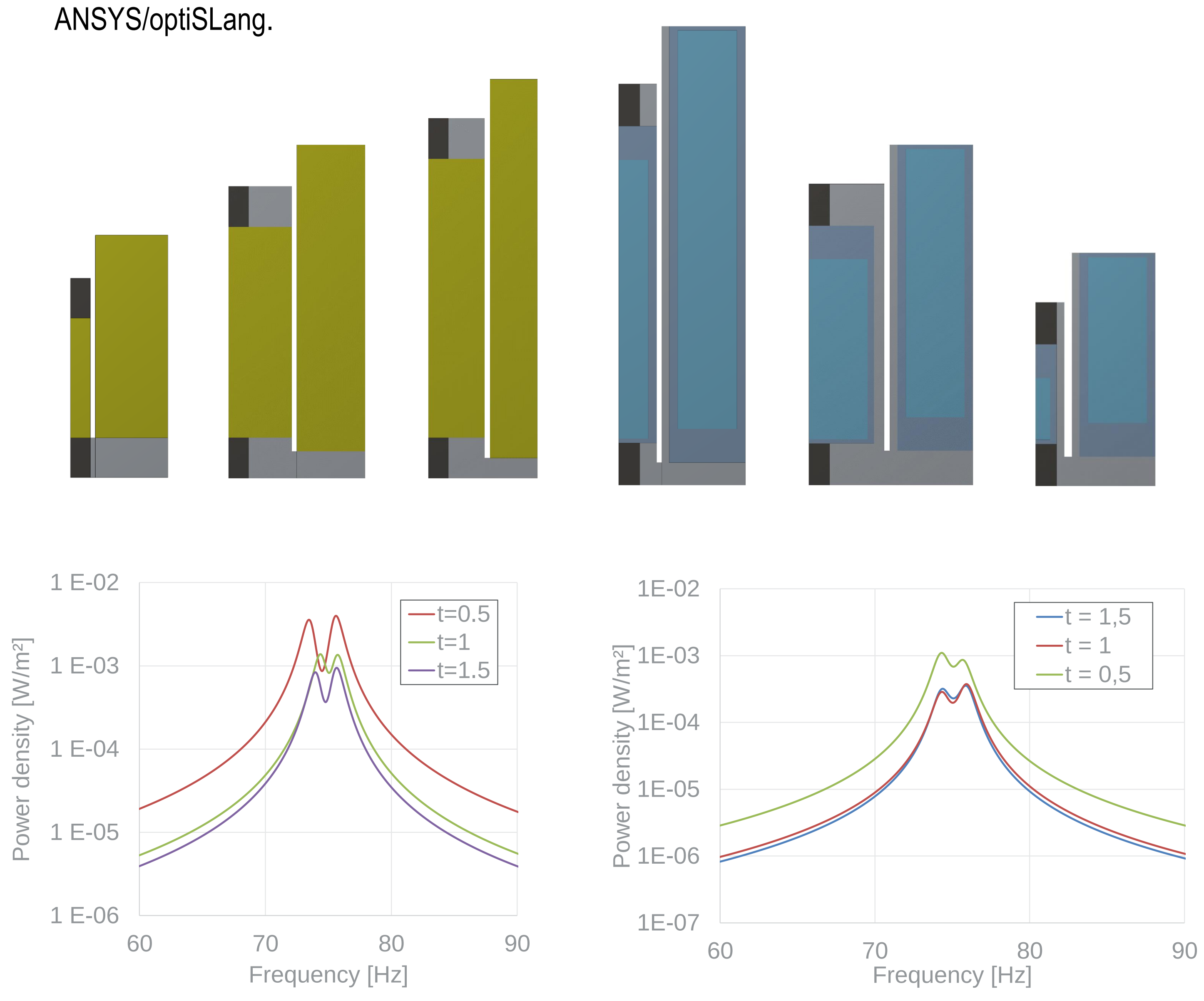


Figure 2: Optimal designs and respective power density plots for classical PZT patches (left) and MFC patches (right).

Outlook

The optimization results will be validated. Therefore, we will fabricate the device in order to obtain experimental results.
Furthermore, we are working on methodologies to increase the efficiency of the optimization, i.e. model order reduction techniques that conserve geometrical parameters, as the optimization process requires unfeasible high amounts of computational effort. Furthermore, we aim to increase the effectiveness of design optimization by involving methods lesser restrictive than parameter optimization, i.e. topology optimization.

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Institute of Electronic Appliances and Circuits | Chair for Micro- and Nanotechnology of Electronic Systems | **University of Rostock**, Albert-Einstein-Str. 2 | 18059 Rostock, Germany

✉ tamara.bechtold@uni-rostock.de