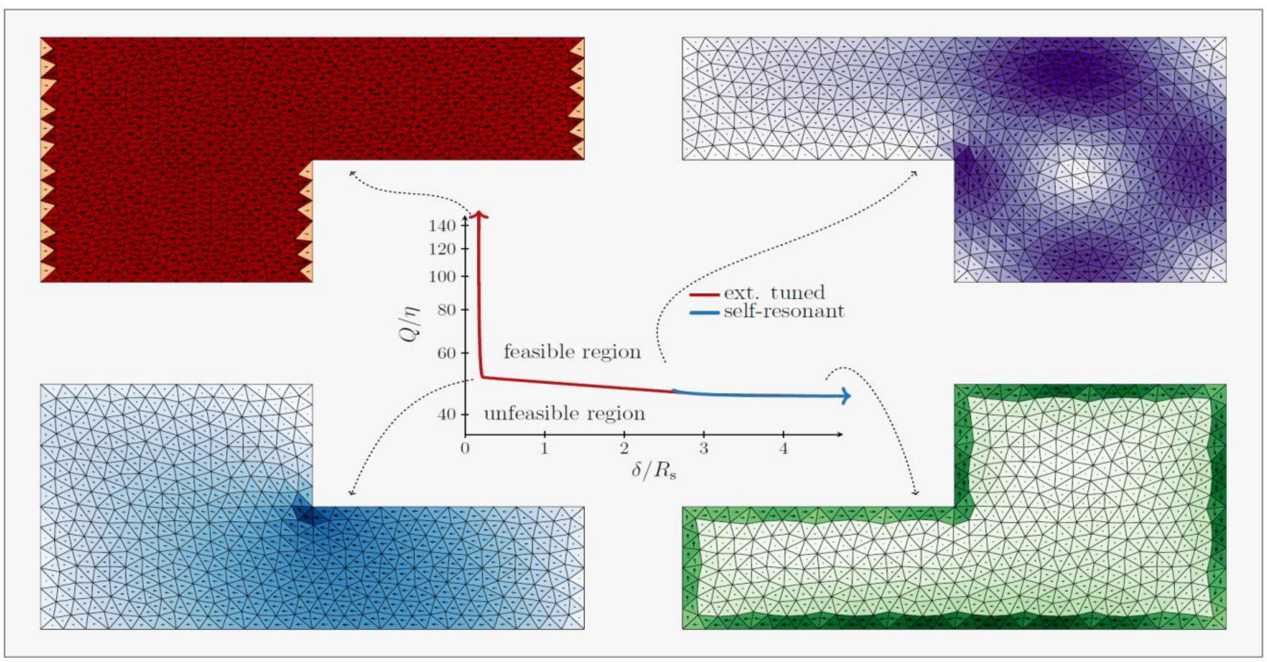
Optimal Inverse Design of Antennas

Abstract

Questions of how good an antenna can be and how to design such antennas are at the core of antenna technology. In this short course, we provide the participants with tools to answer these questions and ultimately design optimal antennas. Optimality is determined from physical bounds which are formulated as optimization problems over the current density. These problems are solved using convex optimization techniques and contribute to a fundamental understanding of the tradeoffs between electrical size, Q-factor, radiation efficiency, gain, and directivity for antennas of arbitrary size and shape. The bounds are compared with classical and optimized antenna designs. Here, we put forward a recently developed technique based on topology optimization in a method of moments setting. This technique is shown to be computationally efficient and able to automatically design antennas with performance close to the physical bounds. Two practical case studies will be completely solved during the course, starting from the definition of relevant metrics, to determination of fundamental bounds, and to optimization of the radiator's shape. The participants will be provided with the presented codes and worksheets summarizing the theory.

The webpage of the course will be released at: https://elmag.fel.cvut.cz/optimaldesign-eucap2023/

Graphical abstract



(Figure can be sent on demand as a vector graphics in PDF.)

Recommended prerequisites

Basic knowledge in MoM is advantageous but not a prerequisite.

Learning objectives

After the course the participant will be able to:

- formulate antenna problems and solve them using convex optimization and quadratically constrained quadratic program (QCQP) techniques,
- determine physical bounds on arbitrarily shaped antenna structures using antenna current optimization,
- understand fundamental trade-offs between electrical size and antenna parameters such as Q-factor, efficiency, gain, directivity, and capacity,
- quantify the cost of extra designing constraints (self-resonance, restricted controllable region,...),
- use software to compute bounds for practical design cases and - if needed - to implement his/her own codes,
- use topology optimization to improve antenna designs and to automate antenna design,
- combine properly local (deterministic) and global (heuristic) approaches to ensure fast convergence towards optimal designs,
- understand unsolved problems in the field and start his/her own research in that area.

The participants will be provided with a set of codes determining the bounds on the antenna metrics (radiation efficiency, Q-factor), and antenna synthesis (Q-factor). A worksheet with analytical solutions will be distributed as well.

Course outline

Design of Optimal Antennas

- (15mins.) Introduction and background of antenna bounds and optimal antennas.

- (30mins.) Integral equations, Method of Moments (MoM) type matrices and mathematical tools (convex optimization, QCQP, model order reduction - characteristic/radiation/stored energy/port modes, Schur complement, ...).

- (60mins.) Physical bounds:

  ✓ antenna current optimization,

- ✓ solutions to the problems of minimum Q-factor and maximum efficiency,
- ✓ overview of solvable antenna problems and their (numerical) complexity,
- ✓ Pareto fronts, trade-offs, cost of resonance,
- ✓ modal representation.

/Break & coffee/

- (35mins.) Automated optimal antenna design:
  - ✓ topology optimization in a MoM formulation,
  - ✓ heuristic optimization methods and hybrid formulations with topology optimization.
- (40mins.) Case studies (from problem setup to solution on paper to numerical implementation and evaluation)
  - ✓ 1/ minimum Q-factor (QCQP solution, mode interpretation, topology sensitivity + heuristics),
  - ✓ 2/ maximum gain (array synthesis, QCQP solution, application of port modes/controllable regions, comparison with Bessel, Hansen-Woodyard).

The participants are expected to bring a laptop and MATLAB if they would like to run the provided codes.

Instructor 1 – biography

Mats Gustafsson received the M.Sc. degree in Engineering Physics 1994, the Ph.D. degree in Electromagnetic Theory 2000, was appointed Docent 2005, and Professor of Electromagnetic Theory 2011, all from Lund University, Sweden.

He co-founded the company Phase holographic imaging AB in 2004. His research interests are in scattering and antenna theory and inverse scattering and imaging. He has written over 100 peer-reviewed journal papers and over 100 conference papers. Prof. Gustafsson received the IEEE Schelkunoff Transactions Prize Paper Award 2010, IEEE Uslenghi Letters Prize Paper Award 2019, and Best Paper Awards at EuCAP 2007 and 2013. He served as an IEEE AP-S Distinguished Lecturer 2013-15.

Instructor 2 – biography

Miloslav Capek was born in Ceske Budejovice, Czech Republic, in March 1985. He received the M.Sc. degree in Electrical Engineering 2009, the Ph.D. degree in 2014, and was appointed Associate Professor in 2017, all from the Czech Technical University in Prague, Czech Republic.

Miloslav is a senior member of the IEEE. He serves as an associate editor of IET Microwaves, Antennas & Propagation. He was a member of the Delegate Assembly of EurAAP between 2015 and 2020 (Group 8). He leads the development of the AToM (Antenna Toolbox for MATLAB) package and serves as a vice-chair of EurAAP “Software and Modeling” working group. He is the author or co-author of more than 120 journal and conference papers. His current research interests include the area of electromagnetic theory, electrically small antennas, numerical techniques, and optimization.
For detailed information see capek.elmag.org.

Key bibliography

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