Newly started software EM project: Antenna Toolbox for MATLAB

7th COST VISTA meeting in Madrid

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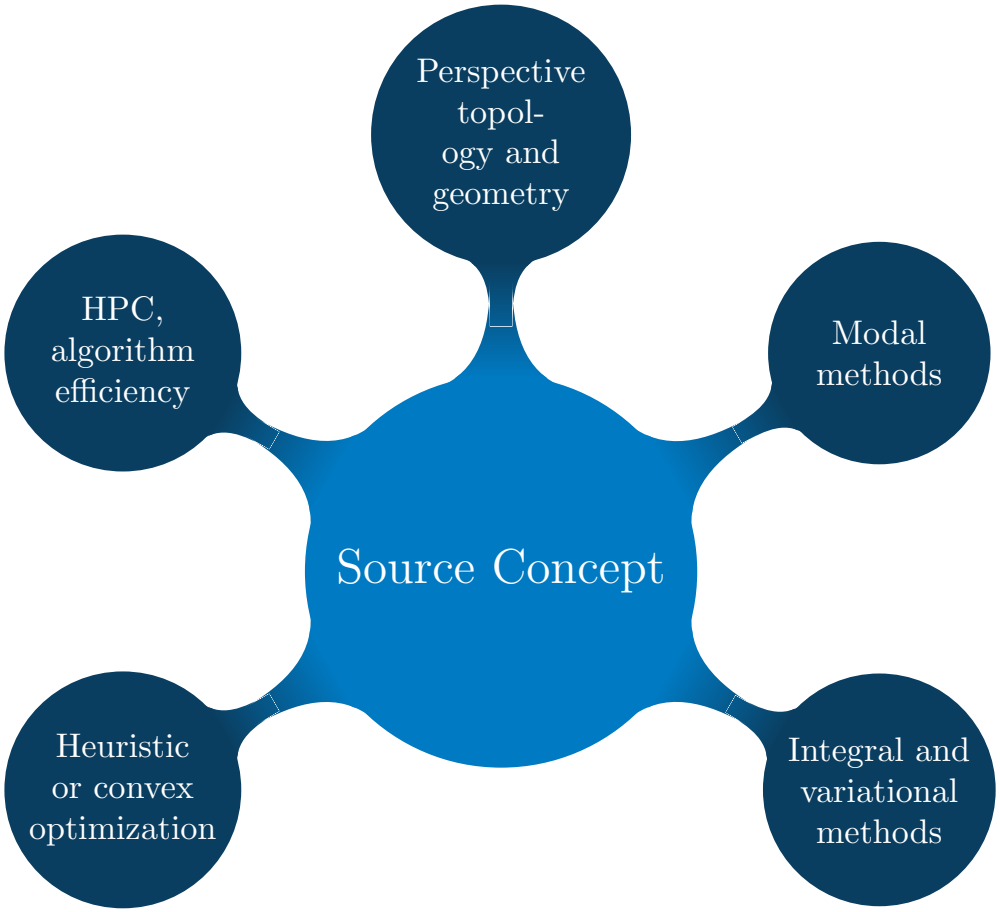
Newly started software EM project

Motivation = to describe newly started project on antenna design

- up-to-date requirements of modern antenna design will be summarized
  - source concept
- as a consequence, new project will be introduced
  - AToM (Antenna Toolbox For Matlab)
  - AToM = transition from scientific code to the commercial toolbox
- project's details will be presented
  - AToM's features

Source Concept

What is actually the Source Concept?



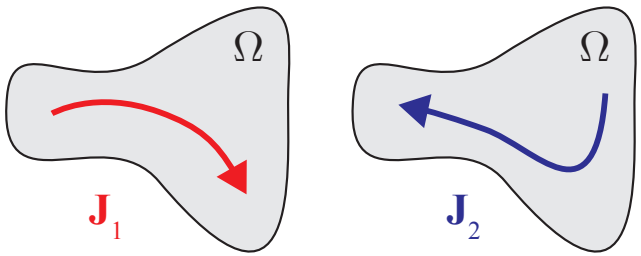
Sketch of main fields of the source concept .

It can be observed that . . .

- an antenna is completely represented by a source current
- all parameters can be inferred from a source current
- any proper int.-diff. operator can be decomposed into modes
- even the source current can be spatially decomposed

Source Concept

Applications: Characteristic Modes



Modes $\mathbf{J}_1$ and $\mathbf{J}_2$ are depicted.

$$\mathbf{J} = \sum_{m=1}^{M} \frac{\langle \mathbf{J}_m, \mathbf{E}^{\mathrm{i}} \rangle}{1 + \jmath\lambda_m} \mathbf{J}_m$$

- characteristic mode (CM) decomposition forms a generalized eigen-value problem[1]:

$$\mathbf{XJ} = \lambda \mathbf{RJ} \tag{1}$$

- CMs are excellent for pattern synthesis[2] or feeding network synthesis[3]
- only FEKO supports CMs
  - only Arnoldi method, no advanced tracking or post-processing

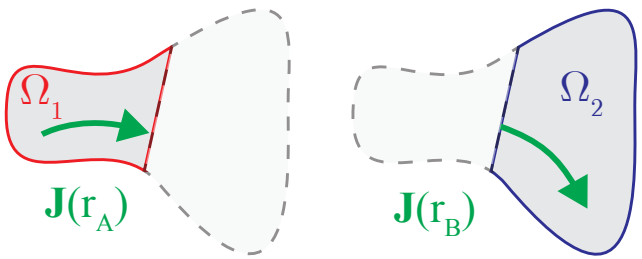
[1] R. F. Harrington and J. R. Mautz. "Theory of Characteristic Modes for Conducting Bodies". In: *IEEE Trans. Antennas Propag.* 19.5 (1971), pp. 622–628. DOI: 10.1109/TAP.1971.1139999

[2] R. F. Harrington and J. R. Mautz. "Pattern Synthesis for Loaded N-Port Scatterers". In: *IEEE Trans. Antennas Propag.* 22.2 (1974), pp. 184–190. DOI: 10.1109/TAP.1974.1140785

[3] M. Capek, P. Hazdra, and J. Eichler. "A Method for the Evaluation of Radiation Q Based On Modal Approach". In: *IEEE Trans. Antennas Propag.* 60.10 (2012), pp. 4556–4567. DOI: 10.1109/TAP.2012.2207329

Source Concept

Applications: Structural Decomposition



Division of Ω into two parts.

$$\mathbf{J} = \bigcup_{k=1}^{K} \mathbf{J}_k$$

- similar to structural decomposition in mechanical engineering
- to decide what part of a radiator stores significant portion of energy / radiates well[4]
- excellent for synthesis of reflect arrays[5]
- combination with CM: sub-structure modes[6]

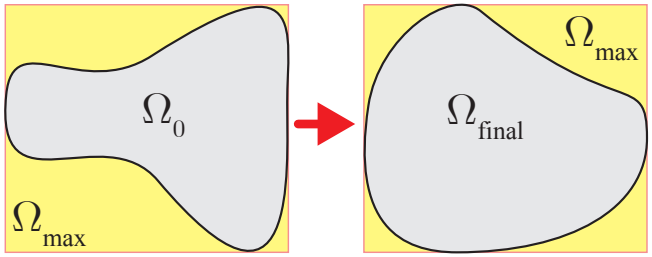
[4] M. Capek et al. "The Measurable Q Factor and Observable Energies of Radiating Structures". In: *IEEE Trans. Antennas Propag.* 62.1 (2014), pp. 311–318. DOI: 10.1109/TAP.2013.2287519

[5] J. L. T. Ethier. "Antenna Shape Synthesis Using Characteristic Mode Concepts". PhD thesis. University of Ottawa, 2012

[6] J. L. T. Ethier and D.A. McNamara. "Sub-structure characteristic mode concept for antenna shape synthesis". In: *Electronics Letters* 48.9 (2012), pp. 471–472. ISSN: 0013-5194. DOI: 10.1049/el.2012.0392

Source Concept

Applications: Optimization



Optimization of antenna's shape.

single-objective optim.:

$$y = \min_{\{x_i\}} \mathcal{F}(\mathbf{J})$$

multi-objective optim.:

$$\{y_j\} = \min_{\{x_i\}} \{\mathcal{F}_j(\mathbf{J})\}$$

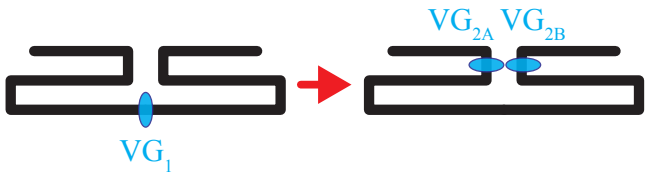
- both single- and multi-objective optimization can be utilized in order to obtain best antenna performance
- many objectives can be subjects of convex optimization[7]
  - $\mathcal{F}(\mathbf{J}, \mathbf{J})$ has to be positive semi-definite[8]
  - convex optimization does not result in specific design, only minimizes given convex function

[7] M. Gustafsson and S. Nordebo. "Optimal antenna currents for Q, superdirectivity, and radiation patterns using convex optimization". In: *IEEE Trans. Antennas Propag.* 61.3 (2013), pp. 1109–1118. DOI: 10.1109/TAP.2012.2227656

[8] S. Boyd and L. Vandenberghe. *Convex Optimization*. Cambridge University Press, 2004

Source Concept

Applications: Advanced Post-processing



Feeding network synthesis.

$$\beta_{m,n} = \Re\{\alpha_m \alpha_n^*\}$$

where:

$$\lambda_m = \frac{\langle \mathbf{J}_m, \mathbf{E}^{\mathrm{i}} \rangle}{1 + \jmath\lambda_m}$$

- any antenna parameter can be defined by functional containing current(s)
- recently derived:
  - radiation efficiency without IBC[9]
  - measurable Q_Z factor[10]
  - energies for sub-wavelength radiators[11] ($ka < 1$)
  - no matter if modal / structural / total current is substituted

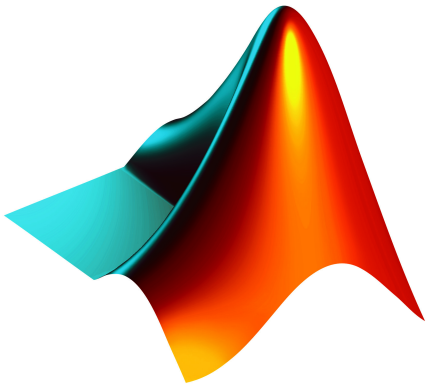
[9] M. Capek, J. Eichler, and P. Hazdra. "Evaluation of Radiation Effciency from Characteristic Currents". In: *IET Microw. Antennas Propag.* (2014). in press

[10] M. Capek et al. "The Measurable Q Factor and Observable Energies of Radiating Structures". In: *IEEE Trans. Antennas Propag.* 62.1 (2014), pp. 311–318. DOI: 10.1109/TAP.2013.2287519

[11] G. A. E. Vandenbosch. "Reactive Energies, Impedance, and Q Factor of Radiating Structures". In: *IEEE Trans. Antennas Propag.* 58.4 (2010), pp. 1112–1127. DOI: 10.1109/TAP.2010.2041166

Source Concept

Requirements: Fast-prototyping Environment



MathWorks MATLAB logo.

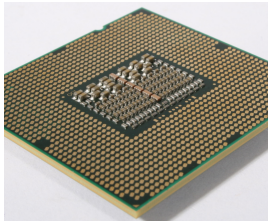
- up to now, there is no commercial package that completely implements techniques mentioned above
- scientists develop and utilize their own codes
  - codes are mainly written in Matlab[12]
  - Matlab is high-definition language for fast-prototyping
  - many built-in functions are embedded
  - new functionality can easily be published[13]
  - Matlab is remarkably cheaper than any multi-physical EM software

[12] The MathWorks. *The Matlab.* URL: www.mathworks.com

[13] www.mathworks.com/matlabcentral/fileexchange

Source Concept

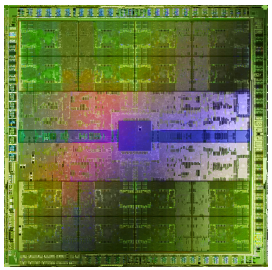
Requirements: Computational Resources



CPU

×

GPU

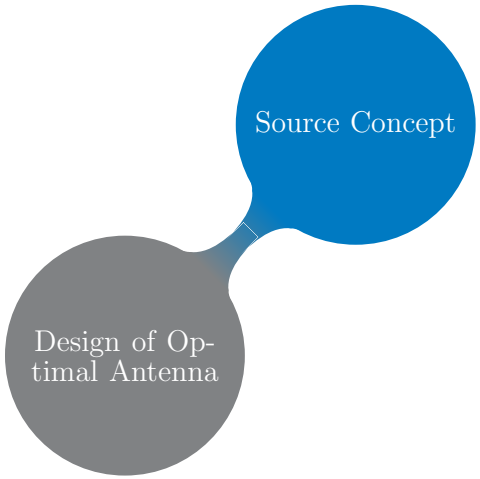


maybe FPGA in the future?

- advanced post-processing and optimization need high-performance computers[14]
- high-performance computing (HPC)
- depending on the nature of the problem
  - CPU can be employed in parallel / distibutive mode
  - GPU can be employed
- Matlab fully supports CPU and GPU acceleration

[14] M. Capek et al. "Acceleration Techniques in Matlab for EM Community". In: *Proceedings of the 7th European Conference on Antennas and Propagation (EUCAP)*. Gothenburg, Sweden, 2013

Design of optimal antenna

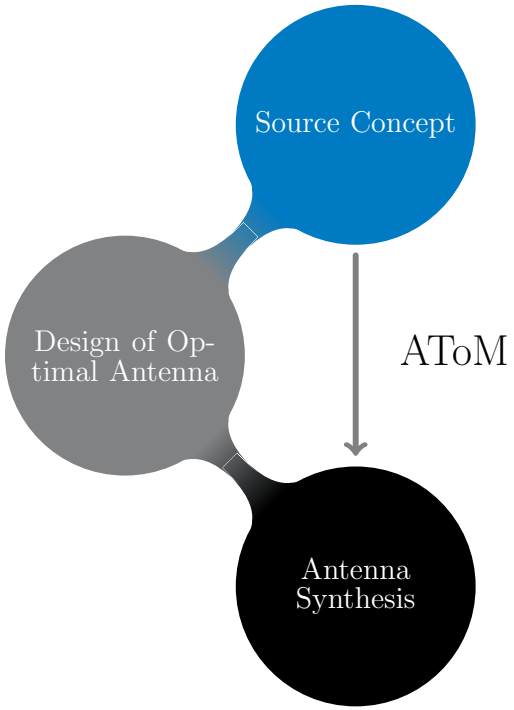


- The source concept was recently utilized for so-called optimal antenna design.
  - see e.g. recent papers by M. Cismasu and M. Gustafsson[15] or by J. Ethier and D. McNamara[16]
- To this purpose, it is beneficial to have a fast prototyping environment with partially open-source code.

[15] M. Cismasu and M. Gustafsson. "Antenna Bandwidth Optimization With Single Freuquency Simulation". In: *IEEE Trans. Antennas Propag.* 62.3 (2014), pp. 1304–1311

[16] J. L. T. Ethier and D. A. McNamara. "Antenna Shape Synthesis without Prior Specification of the Feedpoint Locations". In: *IEEE Trans. Antennas Propag.* PP.99 (2014), p. 1. DOI: 0.1109/TAP.2014.2344107

Design of optimal antenna



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The optimal antenna design leads at least to a partial antenna synthesis!

[15] M. Cismasu and M. Gustafsson. "Antenna Bandwidth Optimization With Single Freuquency Simulation". In: *IEEE Trans. Antennas Propag.* 62.3 (2014), pp. 1304–1311

[16] J. L. T. Ethier and D. A. McNamara. "Antenna Shape Synthesis without Prior Specification of the Feedpoint Locations". In: *IEEE Trans. Antennas Propag.* PP.99 (2014), p. 1. DOI: 0.1109/TAP.2014.2344107

AToM: Antenna Toolbox For Matlab

,,Antenna source concept" – New approach to antenna design.

New EM project AToM (Antenna Toolbox For Matlab) started from September 2014.

Logo of the AToM project.

The main idea behind the AToM toolbox is to develop new package that will be able to:

- utilize the source concept features
- handle with data from third party software
- accept other codes from the community
- make it possible the fast-prototyping of advanced antenna designs

Project Details #1

- web: `antennatoolbox.com`, `antennatoolbox.eu`
  - under construction!!
  - fully operational in 3-4 weeks
- 3 participants
  - CTU in Prague (COST VISTA member, project grant holder)
  - BUT (COST VISTA member)
  - MECAS ESI (subsidiary of ESI Group)
- project's staff
  - Miloslav Capek, Pavel Hazdra, Milos Mazanek, Viktor Adler, Vit Losenicky, Ondrej Kratky
  - Jaroslav Rymus, Vaclav Kleisner et al.
  - Zbynek Raida, Petr Kadlec, Vladimir Sedenka, Jan Puskely, Martin Marek, Lukas Pospisil

Project Details #2

- application to become Matlab Pre-product Partner submitted

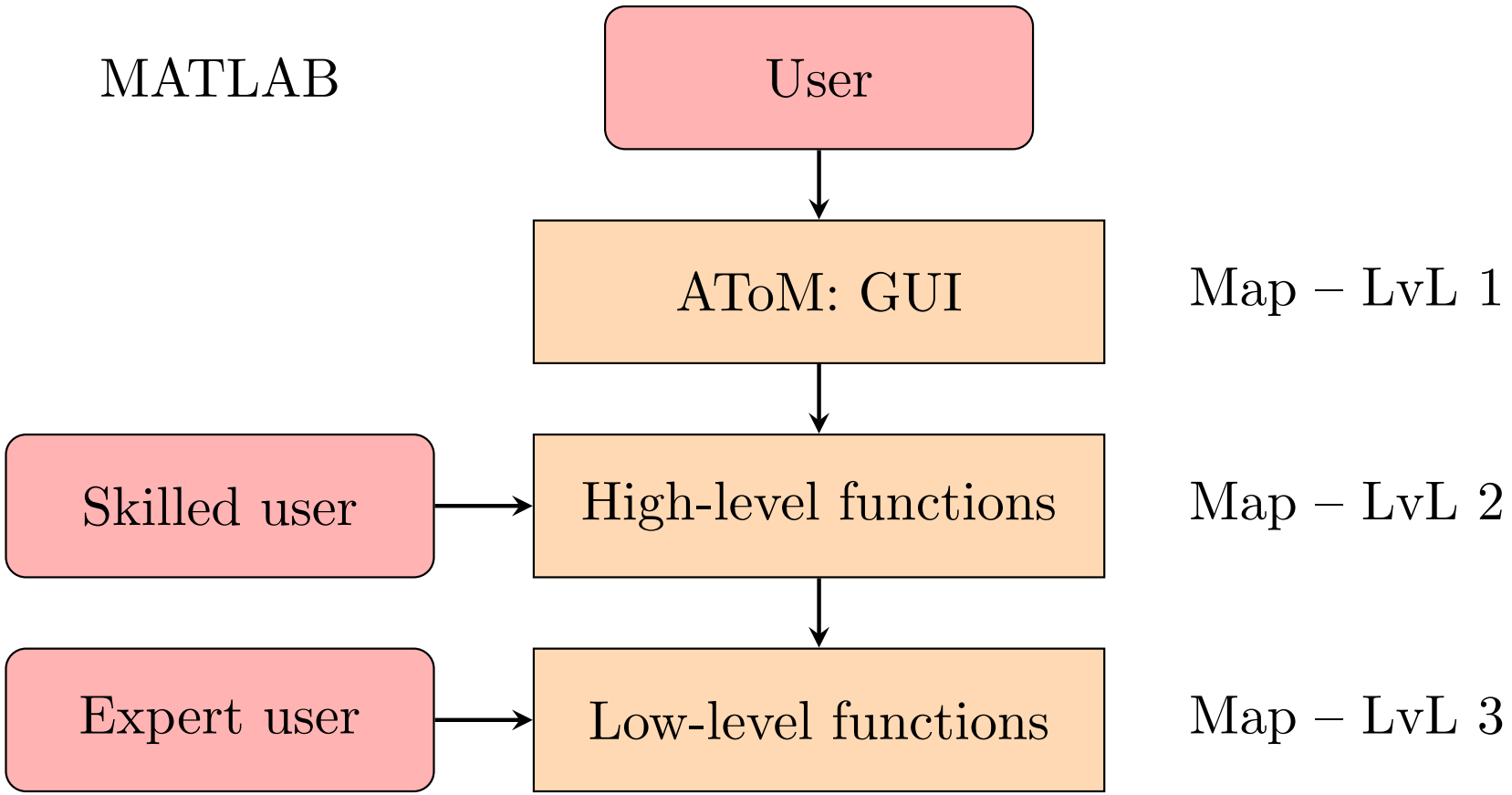
MathWorks | Connections Program

- partially open-source code
  - key parts will be compiled (`.p`-code or `.mex`)
  - new functionality can easily be added by the users
  - detailed documentation of all features
- data storage: HDF5 + Amelet
  - e.g. EDX has no accessible documentation
- support of Technology Agency of the Czech Republic
  - 07/2014 – 12/2017
  - approx. 600 k€

Alfa

$\alpha-$projects logo of Technology Agency of Czech Republic.

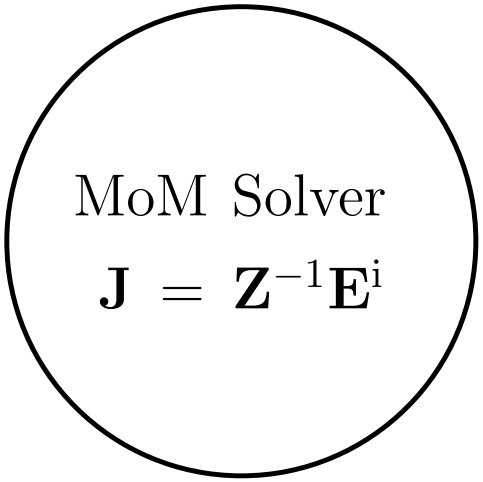
Matlab-like Conception



Scheme of AToM.

Complete EM Software

Structure of AToM:



AToM – 1st level

Complete EM Software

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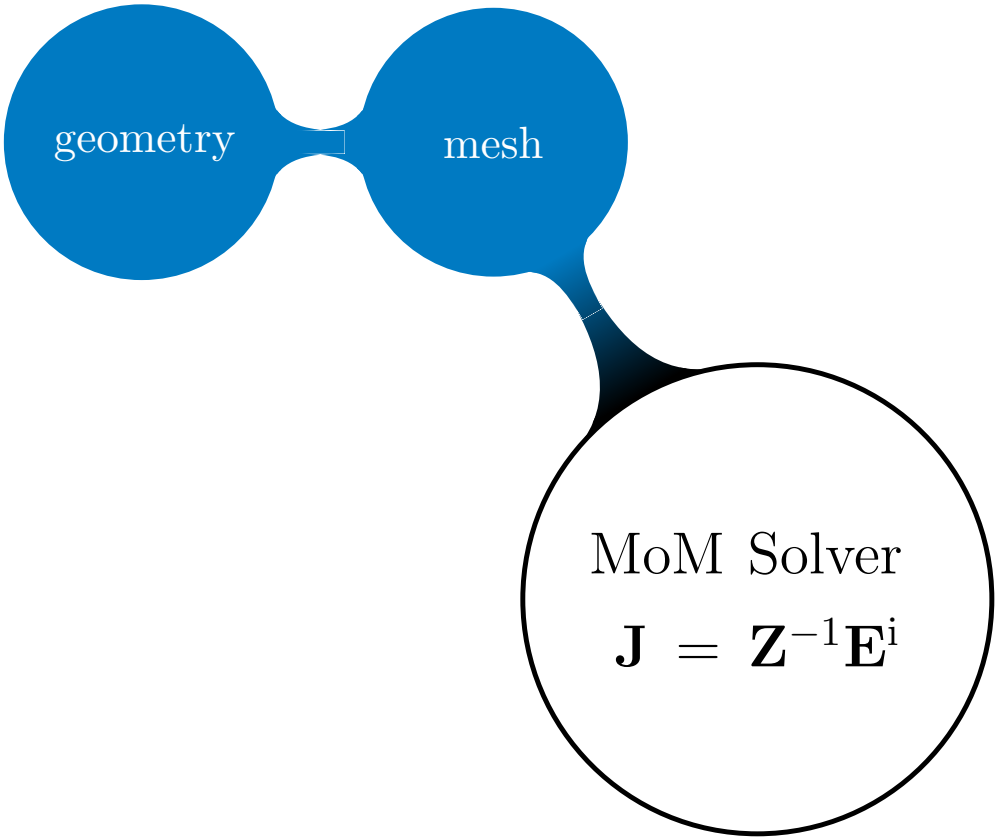

AToM – 1st level

Complete EM Software

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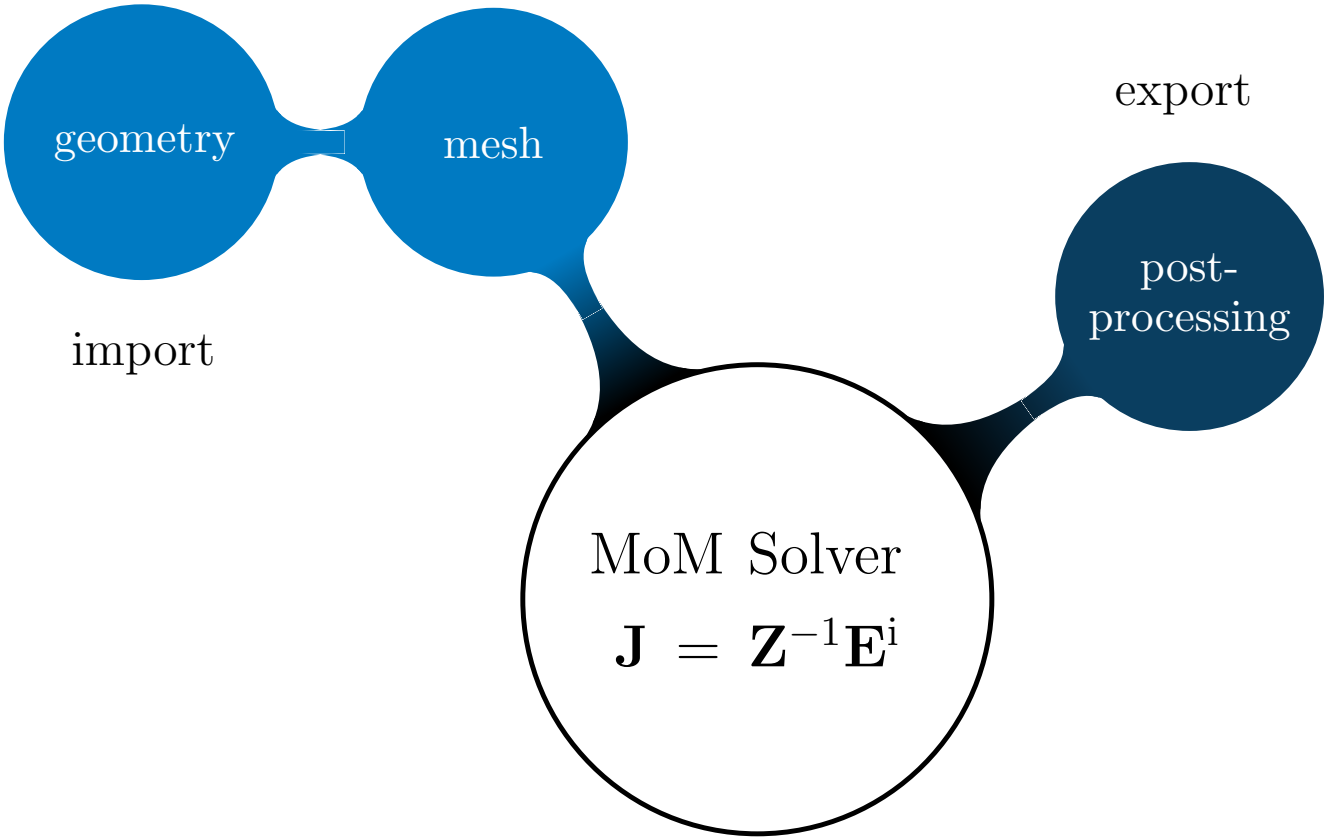
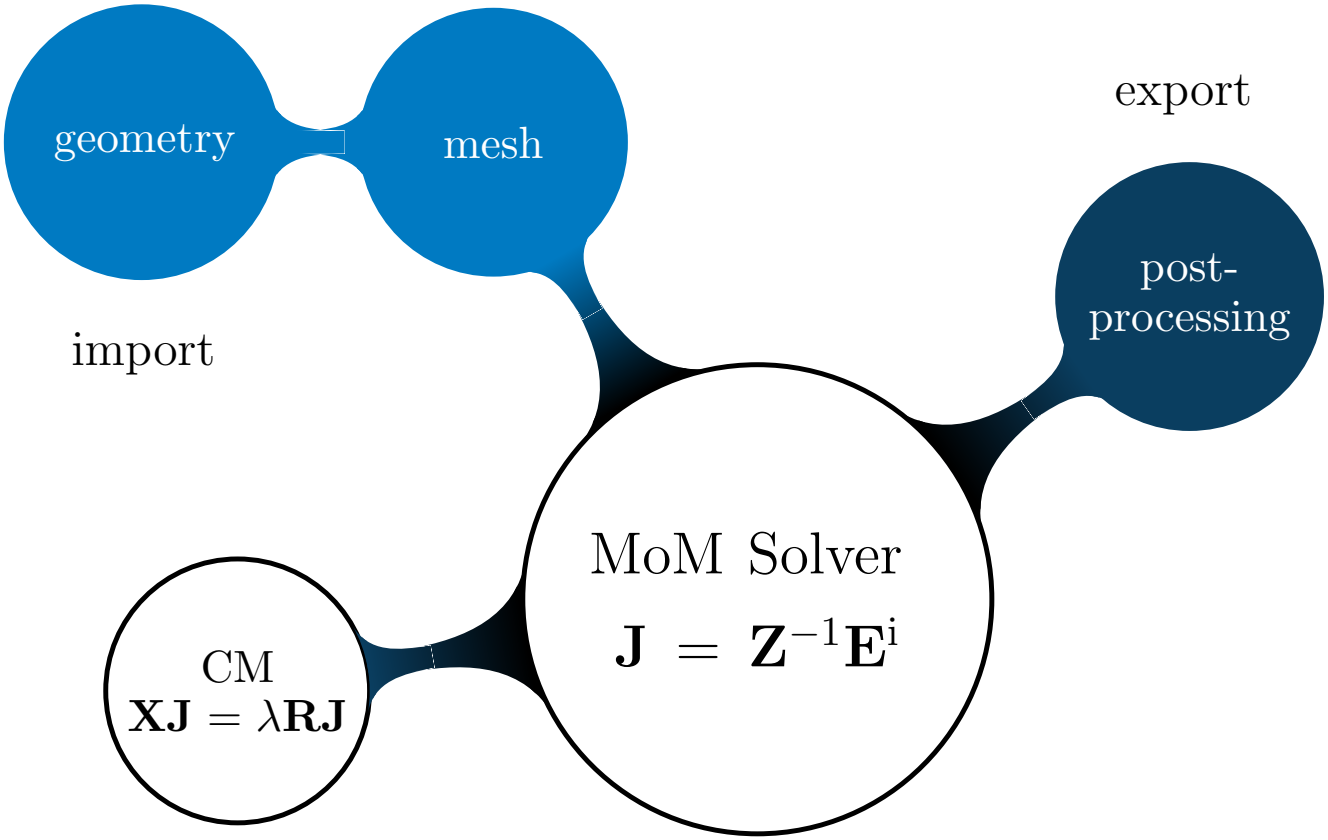


AToM – 1st level

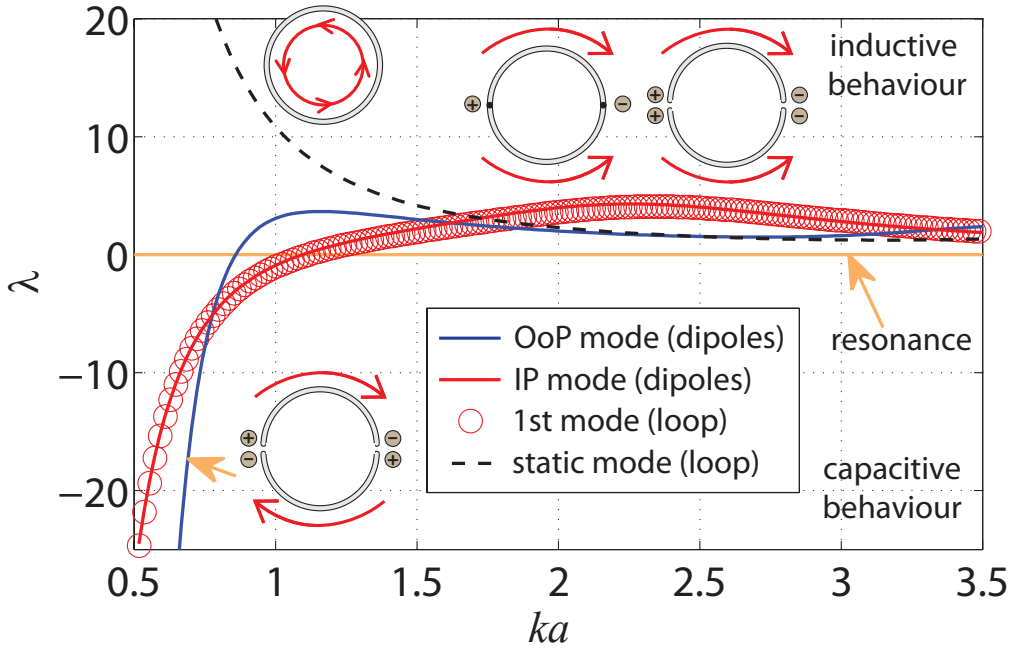
Complete EM Software

Structure of AToM:



AToM – 1st level

Contemporary Techniques #1



Eigennumbers of two dipoles and the loop.

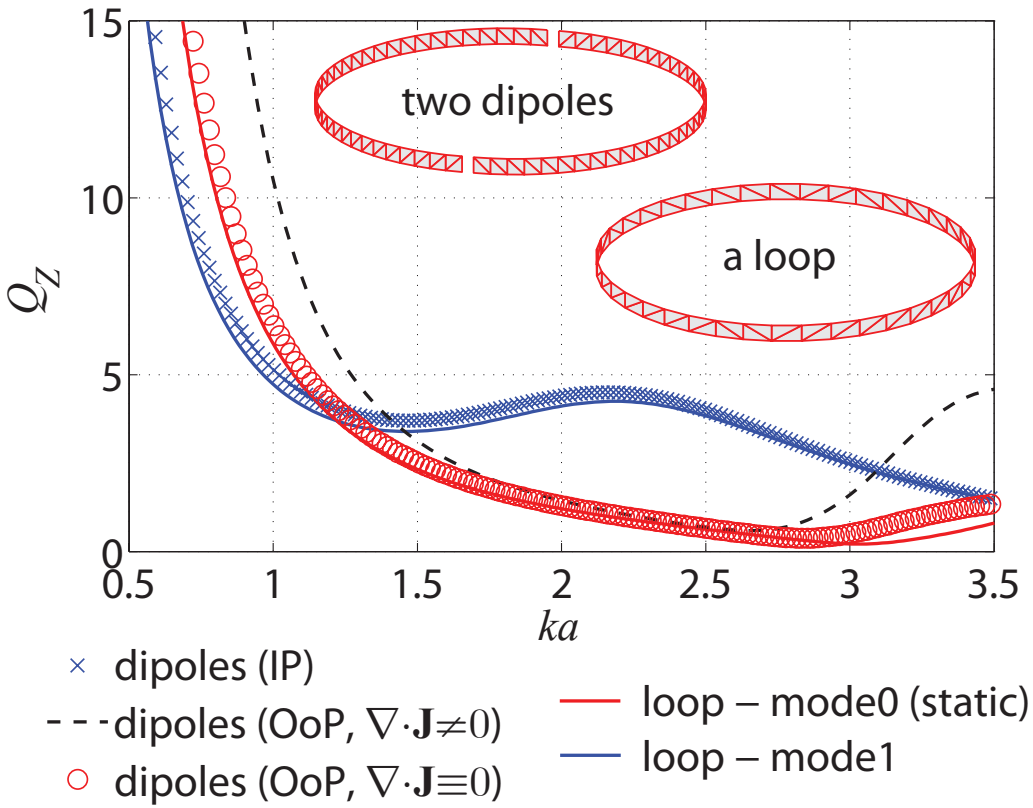
Modal decomposition and current's modifications

- characteristic modes[17] (QZ algorithm, Arnoldi)
- advanced tracking [18]

[17] M. Capek et al. "Implementation of the Theory of Characteristic Modes in Matlab". In: *IEEE Antennas Propag. Magazine* 55.2 (2013), pp. 176–189. DOI: 10.1109/MAP.2013.6529342

[18] M. Capek et al. "A Method for Tracking Characteristic Numbers and Vectors". In: *Progress In Electromagnetics Research B* 33 (2011), pp. 115–134. DOI: 10.2528/PIERB11060209

Contemporary Techniques #2

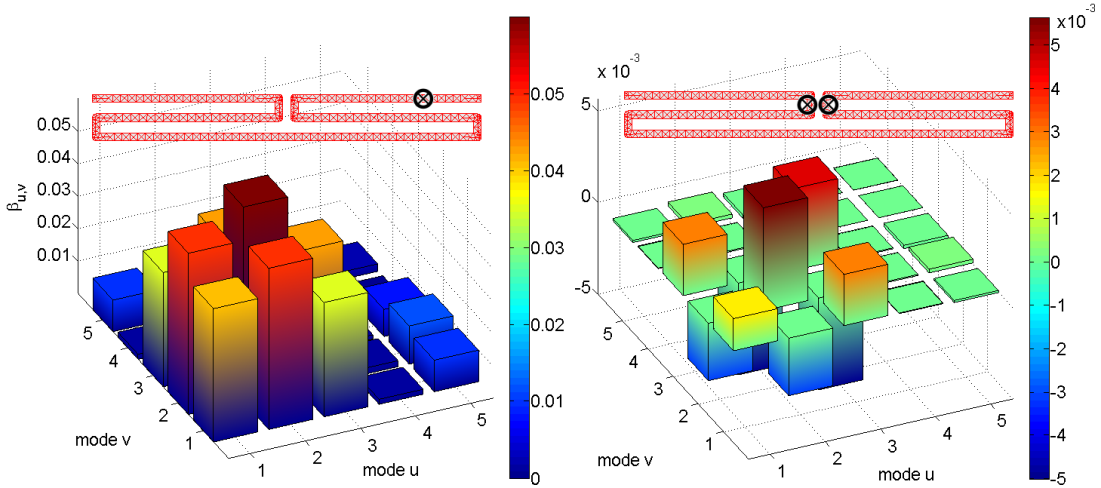


Equivalence of two topologically different structures.

Evaluation of Q_Z based on current densities

- so far, the best estimation of the Q

Contemporary Techniques #3



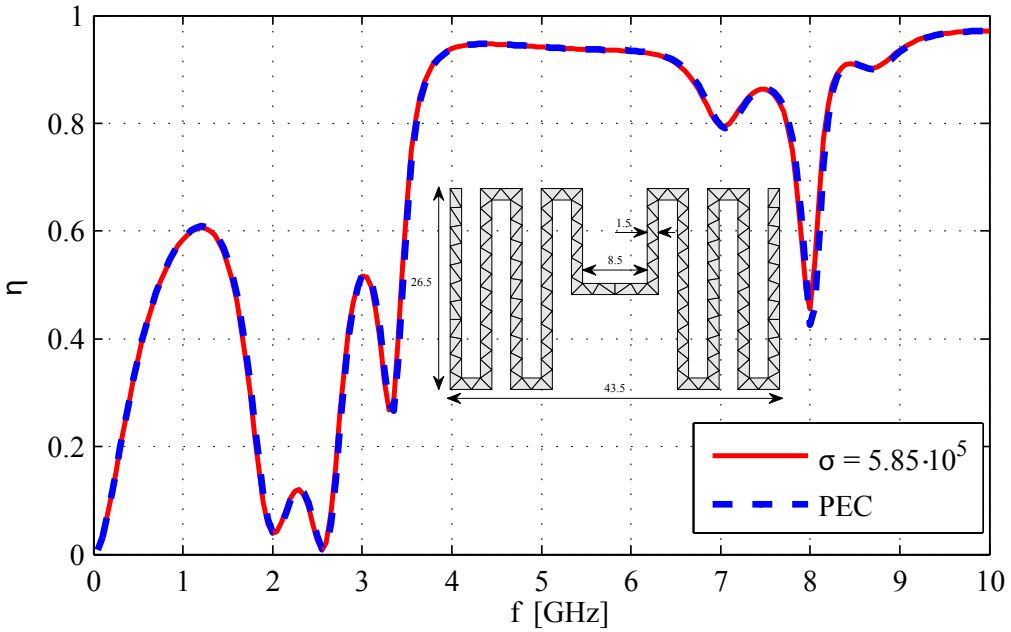
$\boldsymbol{\beta}$ matrix before and after minimization of Q.

Utilization of characteristic modes for synthesis of feeding network[19]

- various goals:
  - minimization of Q
  - desired rad. pattern
  - target input impedance

[19] M. Capek, P. Hazdra, and J. Eichler. "A Method for the Evaluation of Radiation Q Based On Modal Approach". In: *IEEE Trans. Antennas Propag.* 60.10 (2012), pp. 4556–4567. DOI: 10.1109/TAP.2012.2207329

Contemporary Techniques #4



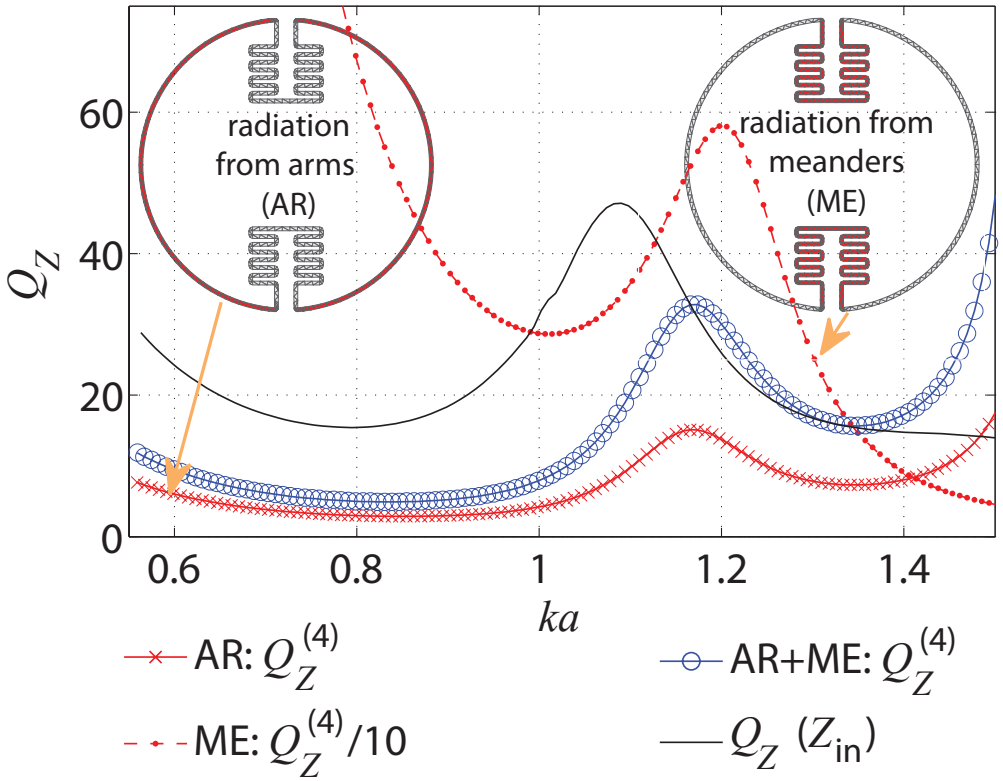
Radiation efficiency of a meandered dipole.

Evaluation of radiation efficiency[20]

- approximation based on current flowing on PEC
- available even for modal currents
- excellent agreement with FEKO (IBC)

[20] M. Capek, J. Eichler, and P. Hazdra. "Evaluation of Radiation Effciency from Characteristic Currents". In: *IET Microw. Antennas Propag.* (2014). in press,
M. Capek et al. "A Method for the Evaluation of Radiation Efficiency Based on Modal Approach". In: *Proceedings of the 8th European Conference on Antennas and Propagation (EUCAP)*. 2014

Scheduled Features



Structural decomposition of U-notched antenna.

Of course, plenty of other features are scheduled:

- calculation of static polarizability[21]
- evaluation of the true stored energy
  - now, AToM is able to evaluate energies according to G. Vandenbosch[22]
- structural decomposition

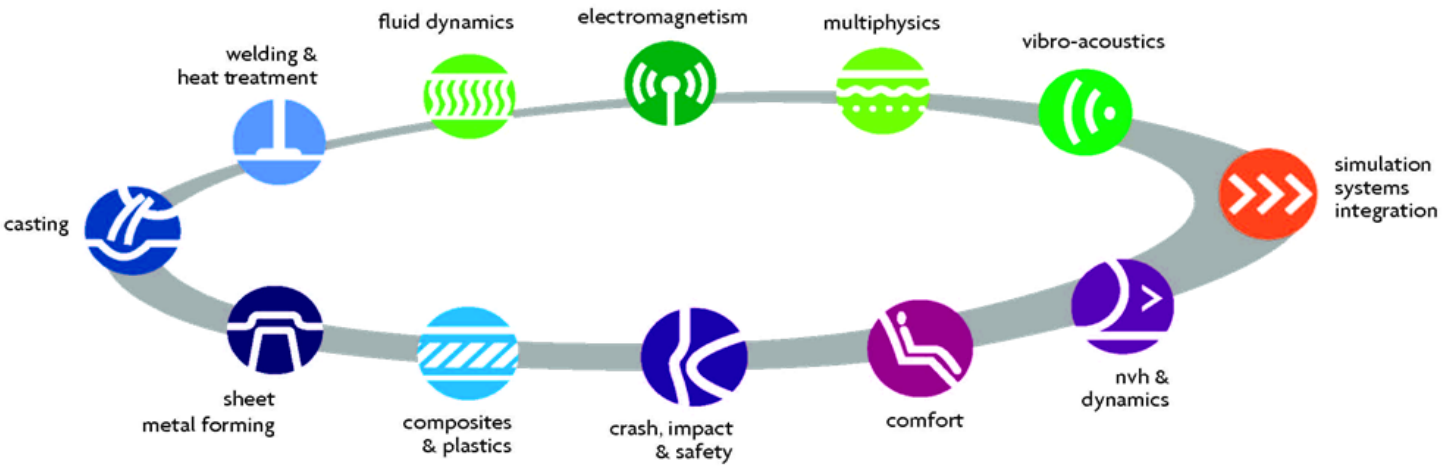
[21] M. Gustafsson, Ch. Sohl, and G. Kristensson. "Illustrations of New Physical Bounds on Linearly Polarized Antennas". In: *IEEE Trans. Antennas Propag.* 57.5 (2009), pp. 1319–1327. DOI: 10.1109/TAP.2009.2016683

[22] G. A. E. Vandenbosch. "Reactive Energies, Impedance, and Q Factor of Radiating Structures". In: *IEEE Trans. Antennas Propag.* 58.4 (2010), pp. 1112–1127. DOI: 10.1109/TAP.2010.2041166

AToM → Visual Antenna

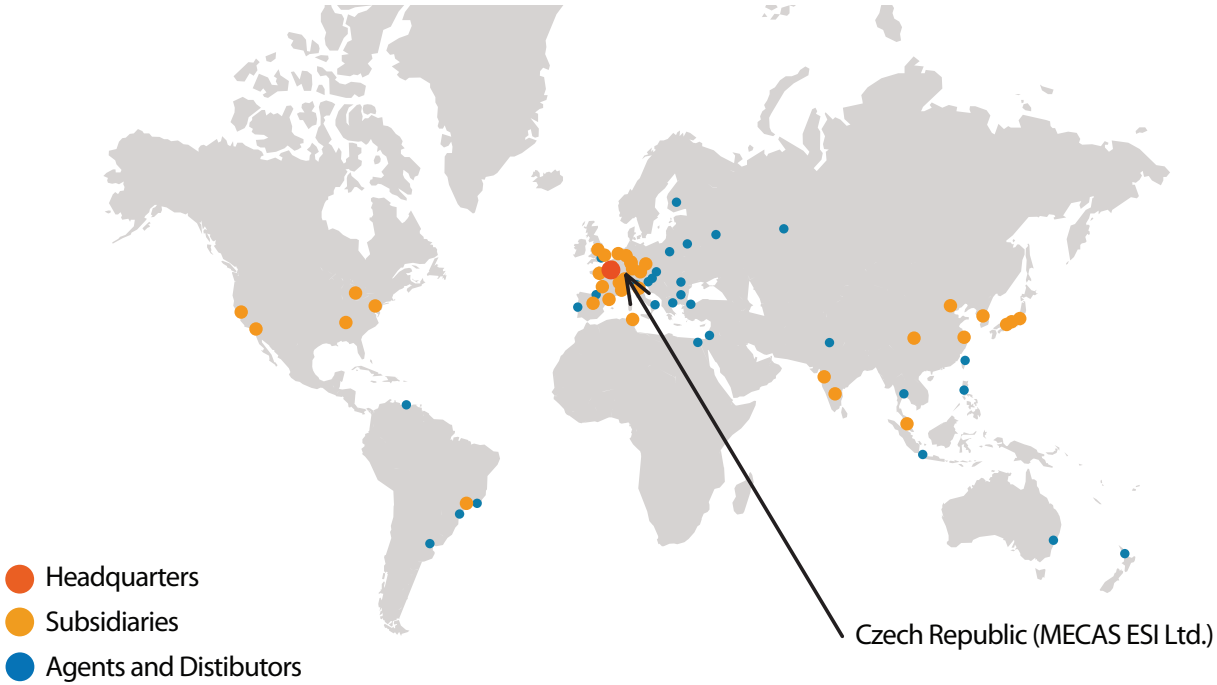
The key functionality of the AToM will be implemented into Visual Antenna package, developed by MECAS ESI company (subsidiary of ESI Group).

- Visual Antenna is a module for Visual CEM[23], which integrates simulation tools for Computational Electromagnetics developed and distributed worldwide by ESI Group
- ESI offers complete solutions for End-to-End Virtual Prototyping



[23] *ESI Group – Visual CEM.* . URL: https://www.esi-group.com/software-services/virtual-environment/electromagnetics

ESI Group and MECAS ESI



- ESI Group has more than 1000 employees, 15 subsidiaries, covers more than 40 countries and operates worldwide
  - we are happy that the whole project is supported by ESI Group and MECAS ESI company, since their support makes it possible to extent the up-to-date antenna techniques to the antenna designers

Thank you!

antennatoolbox.com
miloslav.capek@fel.cvut.cz