Implementation of Characteristic Mode Decomposition and the Source Concept

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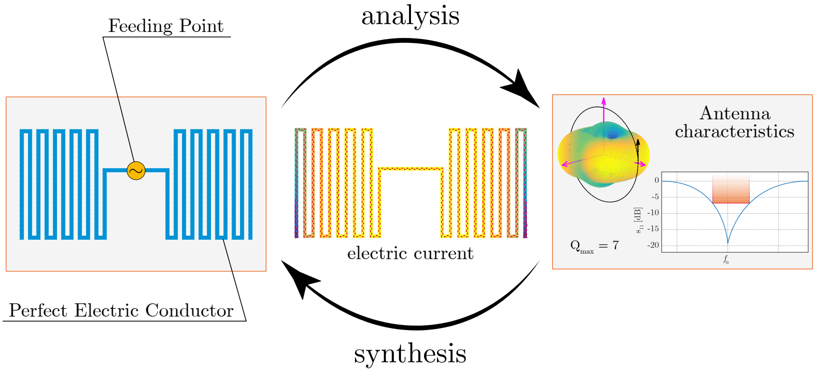
November 12, 2015

[2]Please, see antennatoolbox.com/about-us. The results are based on the collaboration of all members.



Antenna analysis × antenna synthesis.

AToM: Antenna Toolbox For Matlab

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

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

ANTENNA TOOLBOX FOR MATLAB

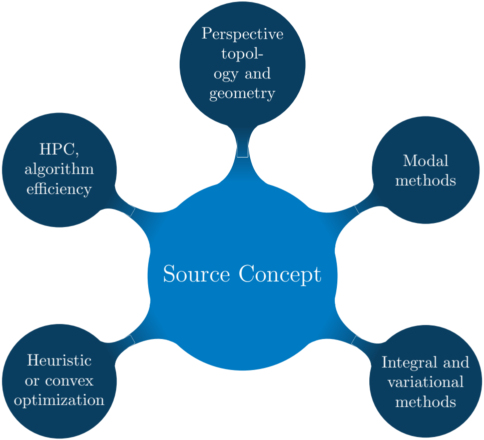
Logo of the AToM project.

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

Source Concept

What is actually the Source Concept?



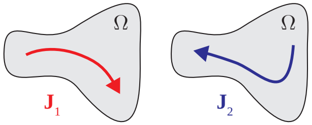
Sketch of main fields of the source concept.

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,
- spatial decomposition of current is possible.

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[3]

$$\boldsymbol{\mathcal{X}} \boldsymbol{J} = \lambda \boldsymbol{\mathcal{R}} \boldsymbol{J} \tag{1}$$

  - other useful decomposition

$$\boldsymbol{J} = \sum_m \gamma_m \boldsymbol{J}_m \tag{2}$$

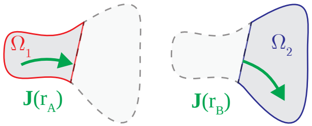
- CMs are excellent for pattern synthesis or feeding network synthesis[4]

[3] 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

[31] 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

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[5]
- excellent for synthesis of reflect arrays[6]
- combination with CM: sub-structure modes[7]

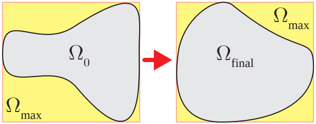
[5] M. Capek et al. “The Measurable Q Factor and Observable Energies of Radiating Structures”. In: *IEEE Trans. Antennas Propag.* 62.1 (2014), pp. 311–318. DOI: 10.1109/TAP.2013.2287519

[6] J. Ethier. “Antenna Shape Synthesis Using Characteristic Mode Concepts”. PhD thesis. University of Ottawa, 2012

[7] 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.:

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

multi-objective optim.:

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

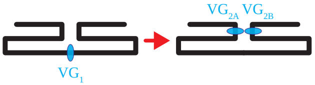
- both single- and multi-objective optimization can be utilized in order to obtain best antenna performance
- many objectives can be subjects of convex optimization[8]
  - $\mathcal{F}(\mathbf{J}, \mathbf{J})$ has to be positive semi-definite[9]
  - convex optimization does not result in specific design, only minimizes given convex function

[8] 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

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

Source Concept

Applications: Advanced Post-processing



Feeding network synthesis.

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

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[10]
  - measurable Q_Z factor[11]
  - energies for sub-wavelength radiators[12] ($ka < 1$)
  - no matter if modal / structural / total current is substituted

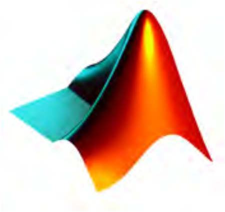
[10] M. Capek, J. Eichler, and P. Hazdra. "Evaluation of Radiation Efficiency from Characteristic Currents". In: *IET Microw. Antennas Propag.* 9.1 (2015), pp. 10–15. DOI: 10.1049/iet-map.2013.0473

[11] 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

[12] 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
- however, scientists develop and utilize their own codes
  - the codes are mainly written in Matlab[13]

[13] The MathWorks. *The Matlab*. 2015. URL: www.mathworks.com

Why Matlab?

Pros

- high-definition language
  - excellent for fast-prototyping
  - many built-in functions are embedded
- new functionality can easily be published[14]
- maybe other. . .

Cons

- still not fast as e.g. C
  - and to be efficient, Matlab needs very good programming skill
- not open-source
- to make standalone application is a nightmare
- maybe other. . .

- What is your opinion??

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

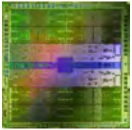
Source Concept

Requirements: Computational Resources

CPU

×

GPU

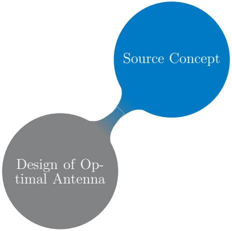


maybe FPGA in the future?

- advanced post-processing and optimization need high-performance computers[15]
  - HPC techniques
- 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
  - implicit acceleration (matrix multiplication, fft,. . .)

[15] 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

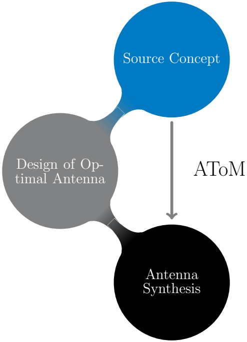


- The source concept was recently utilized for so-called optimal antenna design.
  - see e.g. recent papers by M. Cismasu and M. Gustafsson[16] or by J. Ethier and D. McNamara[17]
- To this purpose, it is beneficial to have a fast prototyping environment with partially open-source code.

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

[17] 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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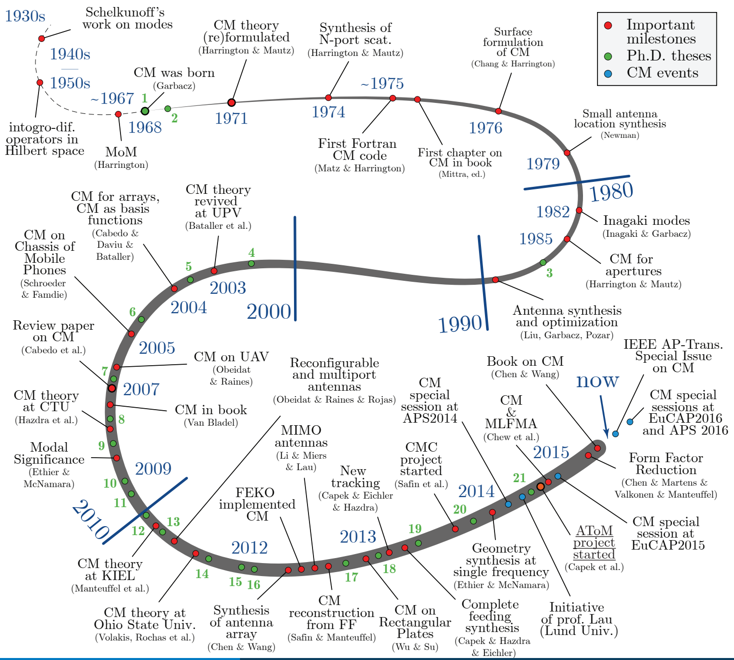
The optimal antenna design leads at least to a partial antenna synthesis!

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

[17] 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

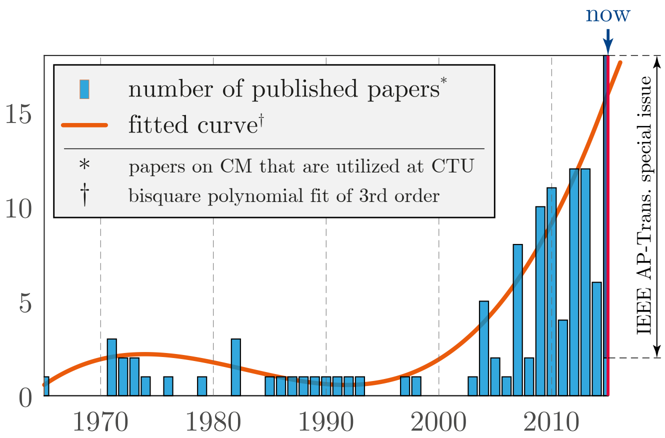
Characteristic mode decomposition



Important milestones
Ph.D. theses
CM events
1930s
Schelkunoff's work on modes
1940s
1950s
intogro-dif. operators in Hilbert space
~1967
1968
MoM (Harrington)
CM was born (Garbacz)
1
2
1971
CM theory (re)formulated (Harrington & Mautz)
1974
Synthesis of N-port scat. (Harrington & Mautz)
~1975
First Fortran CM code (Matz & Harrington)
First chapter on CM in book (Mittra, ed.)
1976
Surface formulation of CM (Chang & Harrington)
1979
Small antenna location synthesis (Newman)
1980
1982
Inagaki modes (Inagaki & Garbacz)
1985
CM for apertures (Harrington & Mautz)
3
1990
Antenna synthesis and optimization (Liu, Garbacz, Pozar)
2000
4
CM theory revived at UPV (Bataller et al.)
5
2003
2004
CM for arrays, CM as basis functions (Cabedo & Daviu & Bataller)
CM on Chassis of Mobile Phones (Schroeder & Famdie)
6
2005
Review paper on CM (Cabedo et al.)
7
2007
CM on UAV (Obeidat & Raines)
CM in book (Van Bladel)
CM theory at CTU (Hazdra et al.)
8
9
Modal Significance (Ethier & McNamara)
2009
10
11
2010
12
13
CM theory at KIEL (Manteuffel et al.)
CM theory at Ohio State Univ. (Volakis, Rochas et al.)
14
15
16
2012
Synthesis of antenna array (Chen & Wang)
Reconfigurable and multiport antennas (Obeidat & Raines & Rojas)
MIMO antennas (Li & Miers & Lau)
FEKO implemented CM
CM reconstruction from FF (Safin & Manteuffel)
New tracking (Capek & Eichler & Hazdra)
2013
17
18
CM on Rectangular Plates (Wu & Su)
19
CMC project started (Safin et al.)
Complete feeding synthesis (Capek & Hazdra & Eichler)
CM special session at APS2014
2014
20
Geometry synthesis at single frequency (Ethier & McNamara)
CM & MLFMA (Chew et al.)
21
2015
Initiative of prof. Lau (Lund Univ.)
AToM project started (Capek et al.)
Book on CM (Chen & Wang)
now
IEEE AP-Trans. Special Issue on CM
CM special sessions at EuCAP2016 and APS 2016
Form Factor Reduction (Chen & Martens & Valkonen & Manteuffel)
CM special session at EuCAP2015

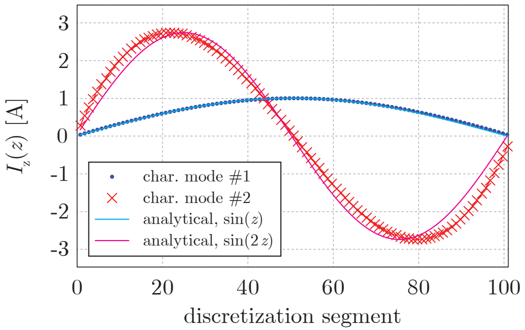
Are CMs nowadays a hype?

$$\mathcal{X} \boldsymbol{J} = \lambda \mathcal{R} \boldsymbol{J}$$



Number of journal papers which are used at CTU to CM development.

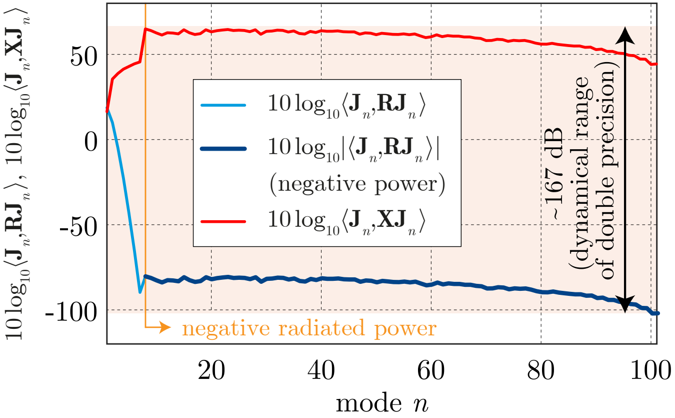
CM theory



Comparison of CMs and sine basis.

- *natural* basis for radiating problems
- forms complete basis for any planar radiator
- ill-posed GEP (generalized eigen-value problem)
  - mainly because of $\boldsymbol{\mathcal{R}}$
  - some eigen-values are negative!
- quite sensitive to non-symmetry of $\boldsymbol{\mathcal{R}}$, $\boldsymbol{\mathcal{X}}$
  - e.g. problem for Makarov's code
  - $\boldsymbol{A} = \frac{1}{2}\left(\boldsymbol{A} + \boldsymbol{A}^{\mathrm{T}}\right), \ \boldsymbol{A} \in \mathbb{R}^{N \times N}$ seems useless
- tracking problems (discussed below)

CM and numerical precision



CM decomposition – numerical dynamics.

CM practice

- alternatives
  - SEM modes
  - $\boldsymbol{\mathcal{X}} \boldsymbol{J} = \kappa \boldsymbol{J}$
  - Inagaki modes[18]
- commercial software
  - FEKO
  - CST (2015)
  - WIPL-D (?)
  - CNC (in-house)
- challenges
  - potential utilization of periodic bound. cond. for CM
  - electrically large structures[19]
  - theory related to the CM
  - tracking

[18] D. Liu. "Some Relationships Between Characteristic Modes and Inagaki Modes for Use in Scattering and Radiation Problems". PhD thesis. The Ohio State Univ., 1986

[19] Q. I. Dai et al. "Multilevel Fast Multipole Algorithm for Characteristic Mode Analysis". In: (2014). URL: http://arxiv.org/abs/1412.1756v2

About AToM

Project Details #1

- 3 participants:
  - CTU in Prague, BUT, MECAS ESI (subsidiary of ESI Group)
- project's staff (from left to right)
  - Miloslav Capek, Pavel Hazdra, Petr Kadlec, Vladimir Sedenka, Viktor Adler, Filip Kozak, Jaroslav Rymus, Milos Mazanek, Zbynek Raida

- students (from left to right)
  - Martin Marek, Ondrej Kratky, Vit Losenicky, Lukas Pospisil

Project Details #2

- antennatoolbox.com
  - source concept[20] (charact. modes, optimization, post-processing)
  - various techniques to evaluate stored energy will be available
- all in Matlab
- YouTube channel
  - AToM's core is almost complete
  - numerical methods (MoM, BEM, CM) are now implemented

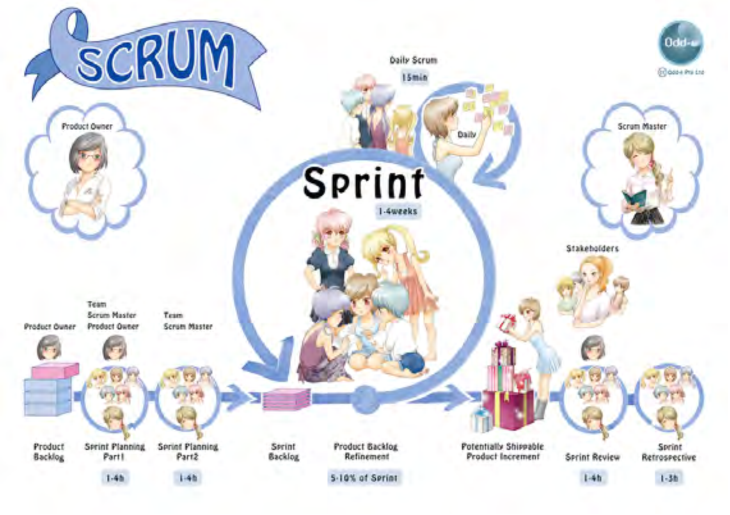
[20] See also the presentations from COST VISTA meetings in Madrid and Nice.

Project Details #3

- application to become Matlab Pre-product Partner submitted
  - however not yet approved...
- 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 – own I/O solution
- support of Technology Agency of the Czech Republic
  - 07/2014 – 12/2017
  - approx. 600 k€

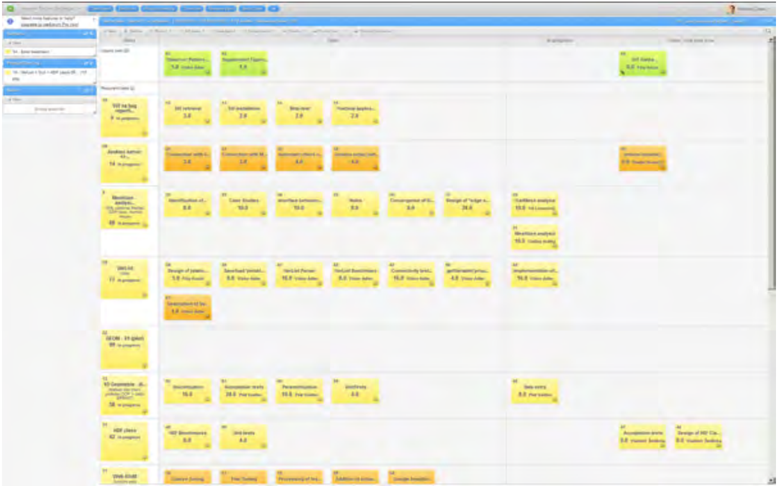
$\alpha-$projects logo of Technology Agency of Czech Republic.

Project's infrastructure – SCRUM



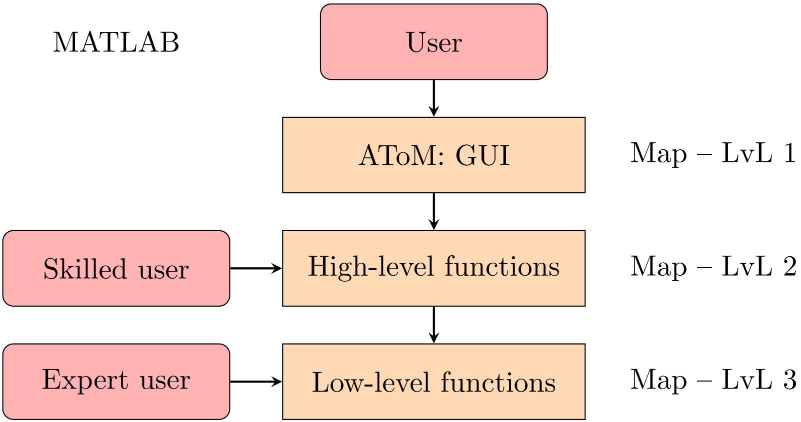
SCRUM – iterative and incremental agile SW development.

Project's infrastructure – iceSCRUM



Open-source iceScrum sofware for Scrum methodology.

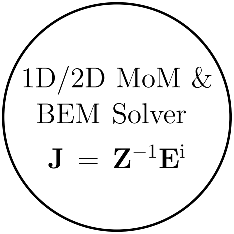
Matlab-like Conception



Scheme of AToM – completely written in OOP.

Complete EM Software

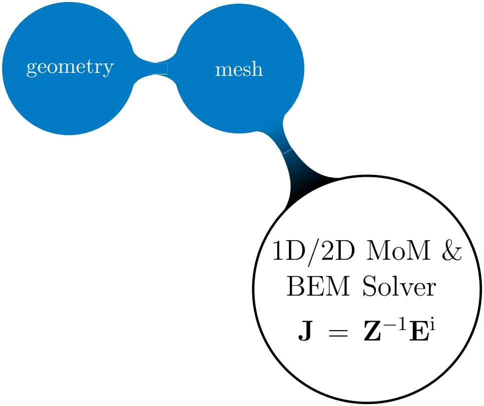
Structure of AToM:



AToM – block diagram

Complete EM Software

Structure of AToM:



AToM – block diagram

Complete EM Software

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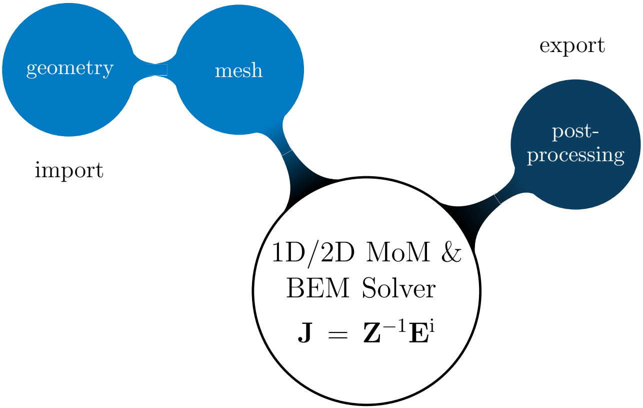
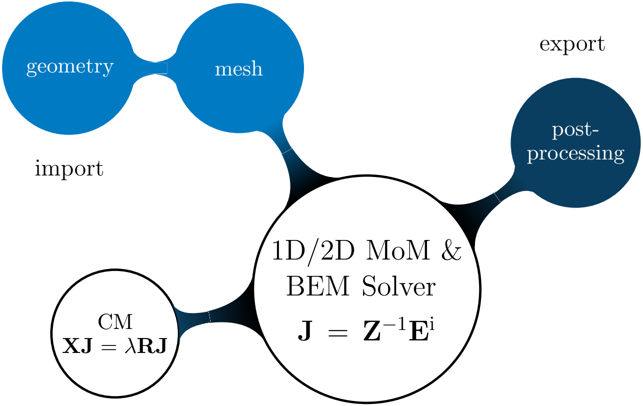


AToM – block diagram

Complete EM Software

Structure of AToM:



AToM – block diagram

Features of Matlab (R2015b)

Did you know?

- Run-time Type Analysis (>Matlab 6.5)
  - data types in m-file are noticed during the first run
- Just-In-Time-Accelerator[21]
  - parts of code that satisfy certain conditions are precompiled
- Object-oriented programming (>R2008)
  - surprisingly rich OOP (all classical OOP patterns feasible)
  - still under development
  - starts to be integrated everywhere (see e.g. in graphics in >R2014a)
- unitTest framework (>2014b)
  - GIT, SVN
- Source Control Integration
  - e.g. Jenkins can be utilized (see later)
- profiling via `profile`
  - JIT however deactivated during the `profile` measurement

[21] See `http://www.ee.columbia.edu/ marios/matlab/accel_matlab.pdf`.

OOP & vectorization

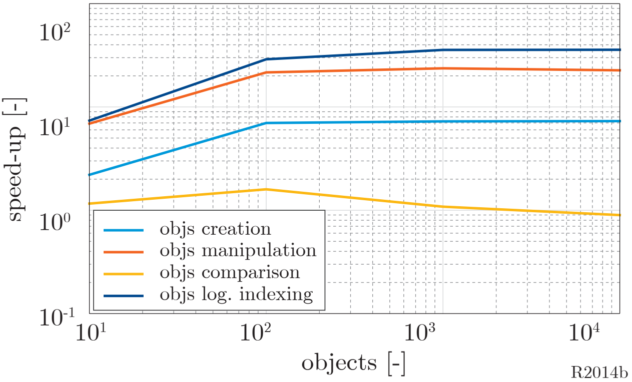
```
% ...
% check whos weight is even number
function val = isWeightEven(objs)
   val = mod([objs.weight],2) == 0;
end

% return "object" who is the oldest one...
function oldest_obj = whoIsTheOldest(objs)
   allAges = [objs.age]; % for acceleration purposes
   oldest_obj = objs(allAges == max(allAges));
end

% increase age of all objects
function objs = increaseAge(objs, incr_age)
   [objs.age] = indexing.listEntries([objs.age] + incr_age);
end
% ...
```

```
% increase age (modification) — FOR approach
for thisObj = 1:N(thisN)
   ppl(thisObj).increaseAge(10);
end
```

```
% increase age (modification) — vectorized approach
ppl.increaseAge(10);
```

OOP and vectorization (highest *level of abstraction* in Matlab).

OOP: `for` × vectorization

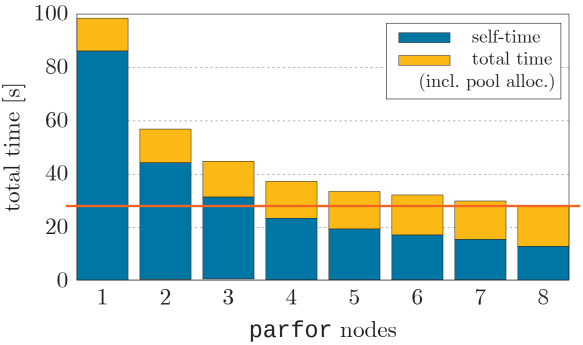


Full OOP code – comparison of `for` and vectorization, warp-up runs skipped, R2014b.

- the speed-up is 150–200% higher in R2015b

GEP (CM): (naive) parallel solver

- e.g. CM cannot easily be accelerated on GPU



- beware of Amdahl's law[22]

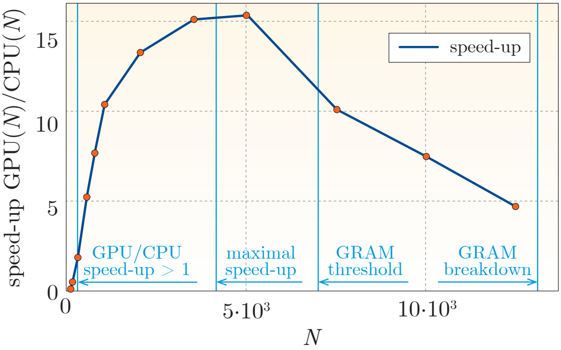
$$S(p, \tau_s) \leq \frac{1}{\tau_s + \frac{1-\tau_s}{p}}$$

CM decomposition parallelized on CPU in Matlab.

[22] T. Larsen. *Parallel High Performance Computing (With Emphasis Jacket Based GPU Computing).* Aalborg University. 2011

Bilinear forms: CPU × GPU

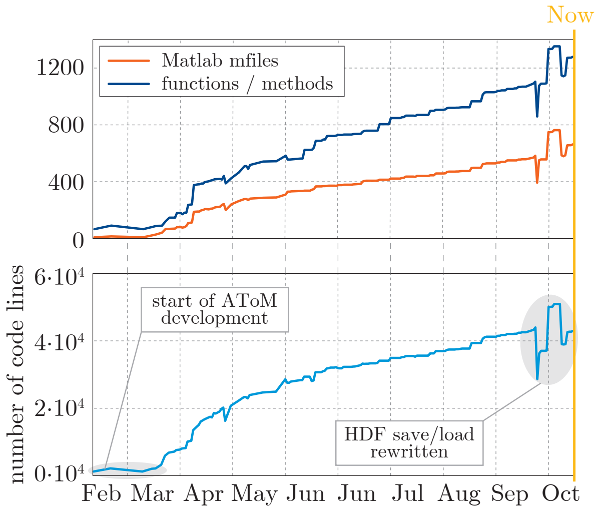
- Matlab R2013a, Jacket + `bsxfun`, GPU card: GTX580



Integration of radiated power as a function of current density discretized into N segments.

$$\mathrm{Pr} = \frac{1}{8\pi\omega\epsilon} \int\limits_{V_1} \int\limits_{V_2} \left(k^2 \boldsymbol{J}(\boldsymbol{r}_1) \cdot \boldsymbol{J}(\boldsymbol{r}_2) - \nabla_1 \cdot \boldsymbol{J}(\boldsymbol{r}_1) \nabla_2 \cdot \boldsymbol{J}(\boldsymbol{r}_2) \right) \frac{\sin(kR)}{R} \, \mathrm{d}V_2 \, \mathrm{d}V_1$$

AToM development – Where we are now?



AToM's statistics – aim at well-balanced development.

directories	43
packages	61
classes	89
m-files	676
functions	1296
unitTests	1014
lines of code	43841
comments	4543

Valid data on 11/11/15, 1:37AM.

- data analysed daily at GIT server by Jenkins

AToM History and Workspace

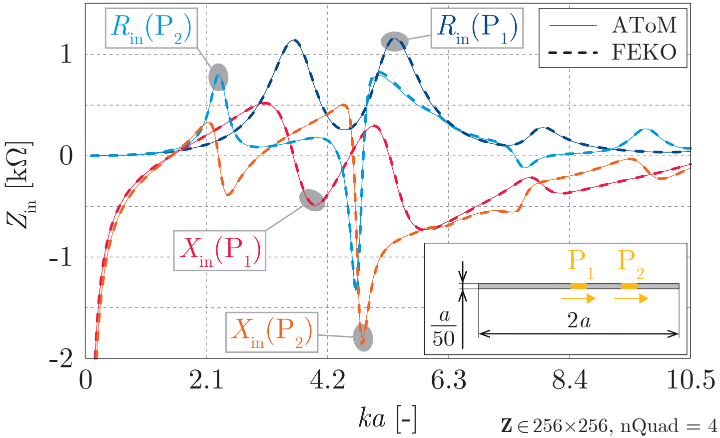
- all actions in AToM are captured (`subsref` overloaded)
  - can be saved as m-file (and modified)
  - full control, can be evaluated as batch
- AToM has own Workspace
  - numerical values can be entered as variables
  - external function can be called to set up particular value
- code-GUI approach like in FEMlab[23] but better than FEMlam

[23] Former Matlab toolbox, now Comsol Multiphysics.

AToM History and Workspace

One of videos from our YouTube channel.

AToM 2D-3D EFIE MoM (Matlab)



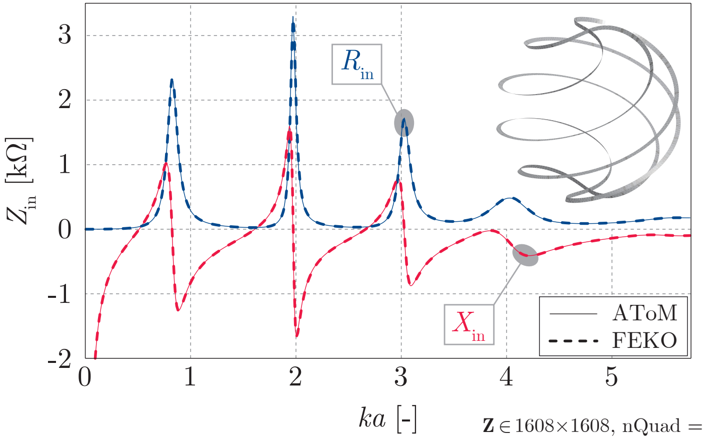
Preliminary results for simple structure (comparison with FEKO).

- multiple feeders

AToM DesignViewer

Presentation of already generated spherical helix in AToM DesignViewer.

Four voltage gaps & RWG junctions



$\mathbf{Z} \in 1608 \times 1608$, nQuad = 1

Preliminary results for more complex structure (comparison with FEKO).

- multiple feeders, 3D surface, junctions

Computational times – Comparison

- the same helix has been calculated both in FEKO and AToM
  - same discretization
  - same number of frequency samples (500)
  - same feeding model

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	total time [s]
FEKO[24]	7302
Makarov[25]	998
AToM[26] (nQuad = 1)	
AToM[26] (nQuad = 2)	

…and the computational time of AToM?

[24] Parallel FEKO has been enabled.

[25] S. N. Makarov. *Antenna and EM Modeling with Matlab.* John Wiley, 2002

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	total time [s]
FEKO[24]	7302
Makarov[25]	998
AToM[26] (nQuad = 1)	933
AToM[26] (nQuad = 2)	1832

[24] Parallel FEKO has been enabled.

[25] S. N. Makarov. *Antenna and EM Modeling with Matlab.* John Wiley, 2002

[26] Implicit Matlab parallelization heavily utilized.

CM decomposition

- we utilize generalized Schur decomposition[27] (`eig`)
- iteratively restarted Arnoldi27 will be implemented (`eigs`)
- powerful tracking[28] (heuristic approach)
  - still can be improved (Pearson formula[29], far-field correlation[30])
- modal quantities[31] ($W_{\mathrm{m}}^{u,v}$, $W_{\mathrm{e}}^{u,v}$, $W_{\mathrm{rad}}^{u,v}$, $P_{\mathrm{r}}^{u,v}$, $D^{u,v}$, $\eta_{\mathrm{rad}}^{u,v}$)
  - all quantities, except radiated power, have cross-terms!

$$\beta_{u,v} = \frac{\langle \boldsymbol{J}_u, \boldsymbol{E}_i \rangle \langle \boldsymbol{J}_v, \boldsymbol{E}_i \rangle \left(1 + \lambda_u \lambda_v\right)}{\left(1 + \lambda_u^2\right)\left(1 + \lambda_v^2\right)}, \quad A = \boldsymbol{\beta} : \boldsymbol{A}_{\mathrm{modal}} \tag{3}$$

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[24] J. H. Wilkinson. *The Algebraic Eigenvalue Problem.* Oxford University Press, 1988

[28] 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

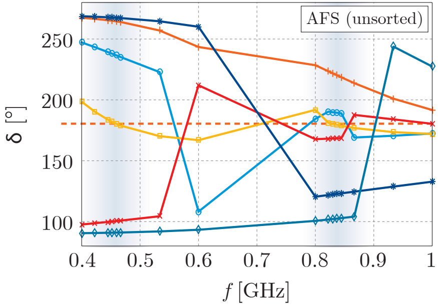
[29] D. J. Ludick, U. Jakobus, and M. Vogel. "A Tracking Algorithm for the Eigenvectors Calculated with Characteristic Mode Analysis". In: *Proceedings of the 8th European Conference on Antennas and Propagation (EUCAP).* 2014, pp. 629–632

[30] Z. Miers and B. K. Lau. "Wide Band Characteristic Mode Tracking Utilizing Far-Field Patterns". In: *IEEE Antennas Wireless Propag. Lett.* 14 (2015), pp. 1658–1661. DOI: 10.1109/LAWP.2015.2417351

[4] 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

Adaptive solver

- adaptive frequency solver (parallelized)
  - we are often interested in results around resonant frequency
  - improvement of tracking
  - acceleration of CM calculation



AFS after 3 iterations, raw data (left), rectangular plate 30 × 20 cm.

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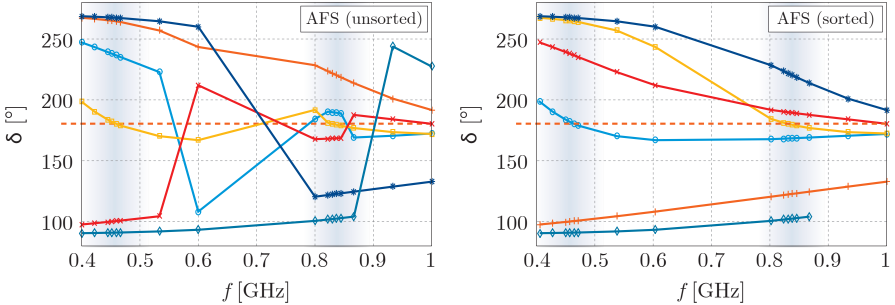


AFS after 3 iterations, raw data (left), sorted data (right), rectangular plate 30 × 20 cm.

FOPS: Fast Optimization Routines

We dispose of in-house

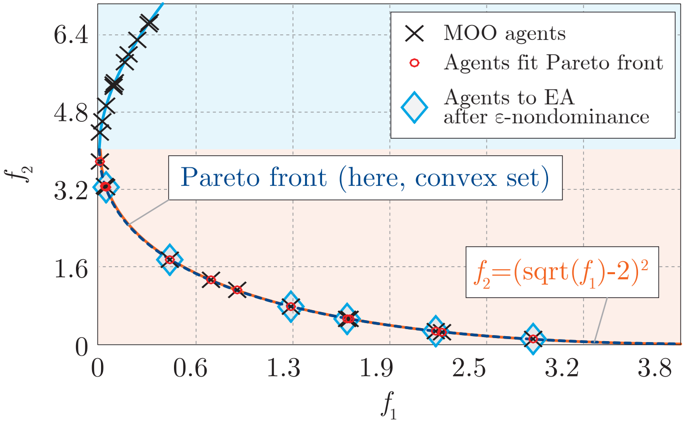
- SOO algorithms
  - Nelder-Mead, PSO, SOMA, GA
- MOO algorithms
  - PSO, SOMA
  - GA is implemented now
- hybrids[32]
  - e.g. Nelder-Mead + PSO (combination of global and fast local optimizers)

$$
\begin{aligned}
v_n^i = & \left(w_i + c_0 \mathrm{rand}_n v_n^{i-1}\right) \\
& + c_1 \mathrm{rand}_n \left(p_{\mathrm{best},k} - v_n^{i-1}\right) + c_2 \mathrm{rnd}_n \left(g_{\mathrm{best},n} - x_n^{i-1}\right) \\
& + c_3 \mathrm{rand}_n \left(g_{\mathrm{NMbest},n} - x_n^{i-1}\right)
\end{aligned}
$$

- all optimizers has general input

[24] D. H. Wolpert and W. G. Macready. "No Free Lunch Theorems for Optimization". In: *IEEE Trans. Evolut. Comp.* 1.1 (1997), pp. 67–82. DOI: 10.1109/4235.585893

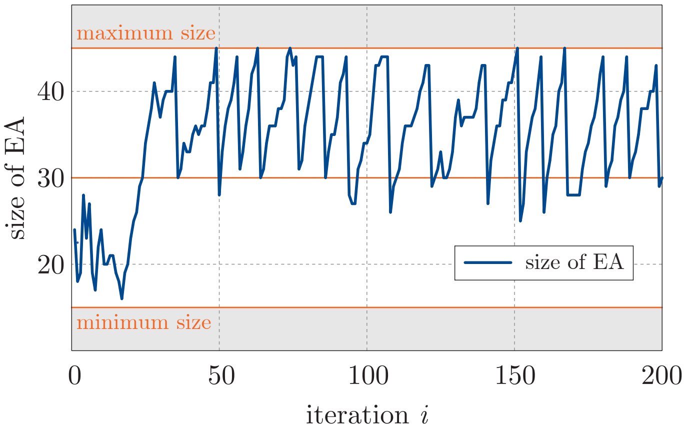
MOO – selection of agent at the front



ϵ-nondominanted solution for Schaffer's 1st problem[33].

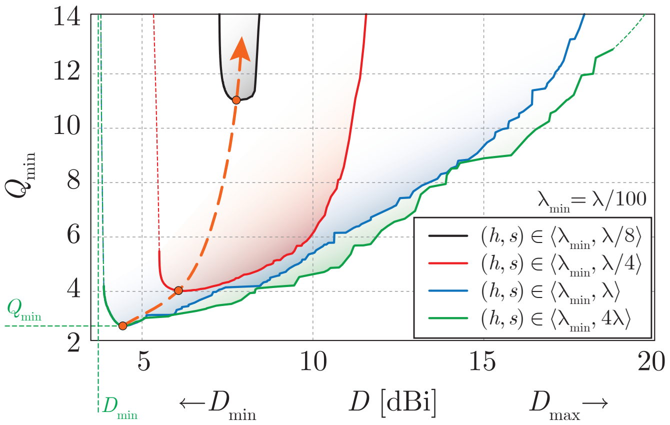
[24] K. Deb. *Multi-Objective Optimization using Evolutionary Algorithms.* John Wiley, 2001

MOO – maintanance of the archive



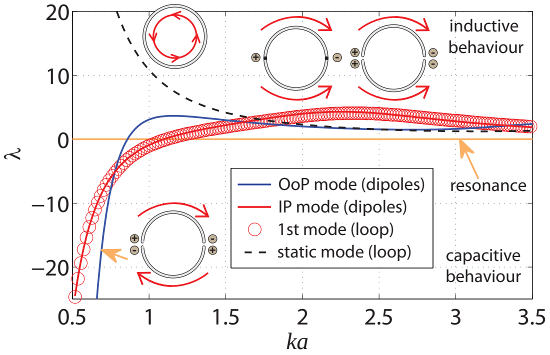
Adaptive maintainance of the external archive for Viennet's 1st problem, 50 agents.

Example of MOO utilization – 4 dipoles



Two dipoles separated by distance s and placed h above PEC plane.

Contemporary Techniques #1



Eigennumbers of two dipoles and the loop.

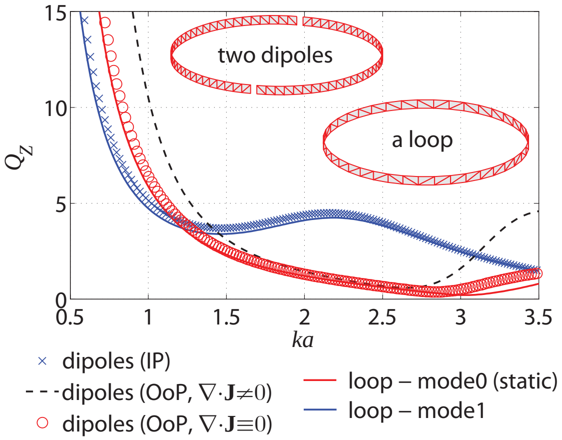
Modal decomposition and current's modifications

- characteristic modes[34] (QZ algorithm, Arnoldi)
- advanced tracking [35]

[34] 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

[35] 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

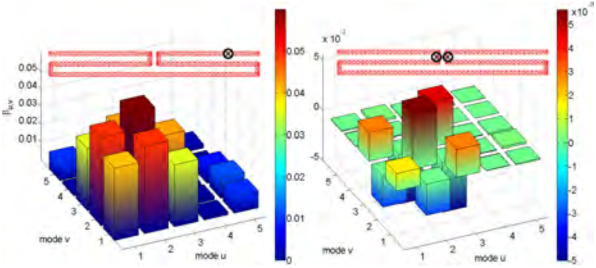


Equivalence of two topologically different structures.

Evaluation of Q_Z based on current densities

- so far, the best estimation of the Q

Contemporary Techniques #3



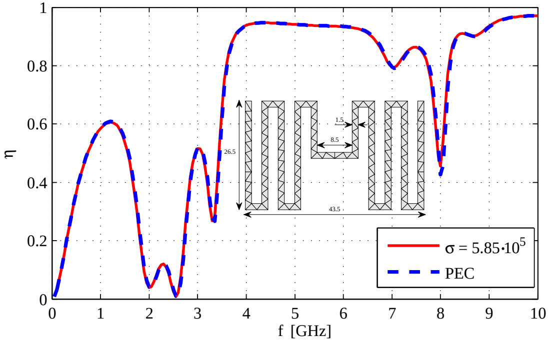
$\boldsymbol{\beta}$ matrix before and after minimization of Q.

Utilization of characteristic modes for synthesis of feeding network[36]

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

[36] 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



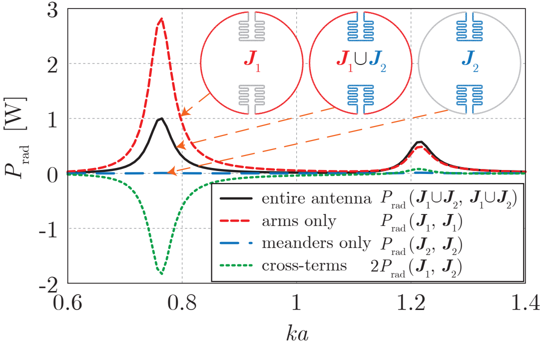
Radiation efficiency of a meandered dipole.

Evaluation of radiation efficiency[37]

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

[37] M. Capek, J. Eichler, and P. Hazdra. "Evaluation of Radiation Efficiency from Characteristic Currents". In: *IET Microw. Antennas Propag.* 9.1 (2015), pp. 10–15. DOI: 10.1049/iet-map.2013.0473, 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

Contemporary Techniques #5

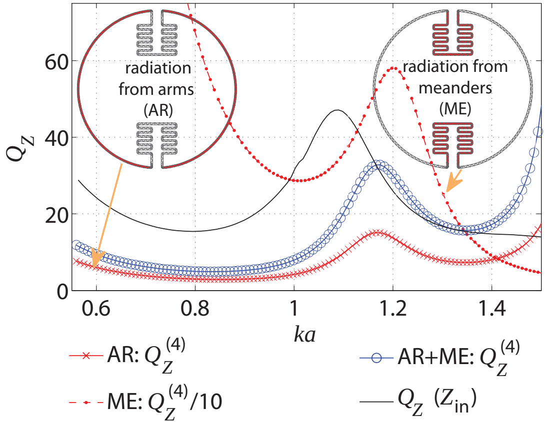


Structural decomposition of double U-notched antenna.

Structural decomposition

- what part of an antenna radiates well?

Scheduled Features



Structural decomposition of U-notched antenna.

Of course, plenty of other features are scheduled:

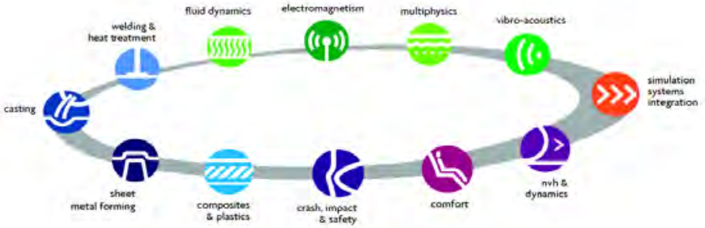
- calculation of static polarizability[38]
- evaluation of the stored energy
- structural decomposition

[38] 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

AToM → Visual Antenna

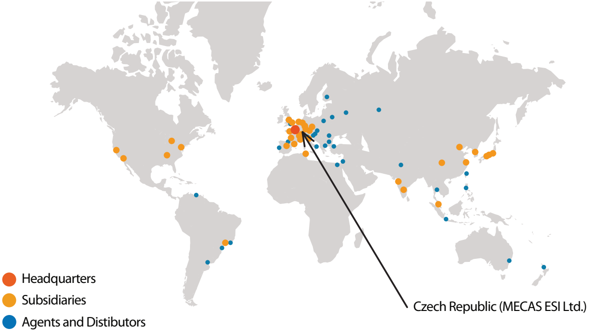
The key functionality of the AToM will be implemented into Visual Antenna package, developed by MECAS ESI company (subsidiary of ESI Group).

- Visual Antenna is a module for Visual CEM[39], which integrates simulation tools for Computational Electromagnetics developed and distributed worldwide by ESI Group
- ESI offers complete solutions for End-to-End Virtual Prototyping



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

ESI Group and MECAS ESI



- ESI Group[40] has more than 1000 employees, 15 subsidiaries, covers more than 40 countries and operates worldwide.

[40] 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!

For complete PDF presentation see ▸ capek.elmag.org

antennatoolbox.com
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