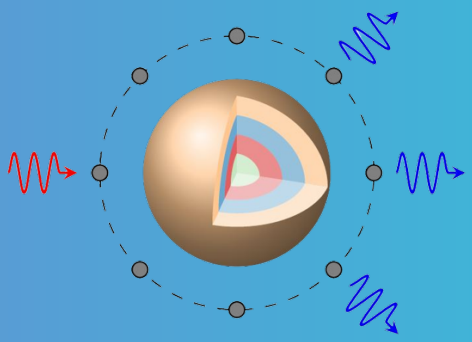

Characteristic Modes Special Interest Group

Newsletter, Volume 3, Number 2, June 1st, 2023

In This Issue:

Scholar Spotlight:

Miloslav Capek (Czech Technical University in Prague), **Mats Gustafsson** (Lund University), **Lukas Jelinek** (Czech Technical University in Prague), **Johan Lundgren** (Lund University) and **Kurt Schab** (Santa Clara University) have collaborated on projects related to electromagnetic theory and antenna design since 2016. Their previous collaborative research focused on bounds and optimal design in various areas of electromagnetics, from antenna design to photonics to cloaking. During the last several years, their work also covers many aspects of scattering-based characteristic mode analysis.

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Featured Article

Scattering-based Characteristic Modes
Tutorial using MATLAB and Commercial Solvers

by Miloslav Capek, Mats Gustafsson, Lukas Jelinek, Johan Lundgren, and Kurt Schab

In the previous edition of this newsletter (Vol. 3, No. 1, March 2023), we summarized our recent work on scattering formulations of characteristic modes. This follow-up volume is a tutorial on the implementation of scattering-based characteristic mode analysis in several commercial software packages.

Code repositories.
Example codes are posted in three public GitHub repositories. The codes utilize MATLAB as a scripting language to control several commercial solvers before calculating characteristic modes from scattering data. The codes can be accessed through the following links.

1. **Scattering Dyadic Method (HFSS, COMSOL, FEKO, CST)**
   https://github.com/kschab/scattering-dyadic-characteristic-modes
2. **Transition Matrix Method (COMSOL)**
   https://github.com/kschab/transition-matrix-characteristic-modes
3. **Matrix-free Method (algorithm only)**
   https://github.com/kschab/iterative-characteristic-modes

Procedure outline.
The core of the scattering-based approach is the construction of a matrix describing the scattering properties of an object under test. This can be implemented in arbitrary in-house and commercial solvers, and examples utilizing COMSOL Multiphysics, HFSS, FEKO, and CST Studio are provided in the scattering dyadic and transition matrix repositories (linked above). The method is also compatible with matrix-free simulation techniques, *e.g.*, MLFMA and FDTD. Implementation details differ between solvers; however, the calculation of the matrix describing an object's scattering behavior can be broken down into three primary steps, illustrated in Fig. 1. First, the model being studied is defined (**1a**), along with a basis for representing incident and scattered fields (**1b**), such as a set of plane waves or spherical vector waves. Afterward, a full-wave electromagnetic (EM) solver is repeatedly called to obtain the scattered fields under a variety of incident field configurations (**2**). The scattering responses from these solutions are collected to form a matrix (**3**), and from this matrix, characteristic modes can be computed (**4**).

An alternative, matrix-free method, described in [4], can be used to accelerate the procedure by reducing the necessary number of calls to a full-wave EM solver. An example of this algorithm using pre-computed scattering and impedance data can be found in the matrix-free method repository (linked above).

Tutorial.
As a demonstration of this method, consider the example of a multi-layered sphere consisting of magnetic and dielectric materials. Details of the problem are given in Sec. IV-C of [3]. This example cannot be analyzed using the built-in CM solver in FEKO. Nevertheless, the scattering of incident waves from this setup can be analyzed using FEKO's built-in hybridization of integral equations and the finite element method.

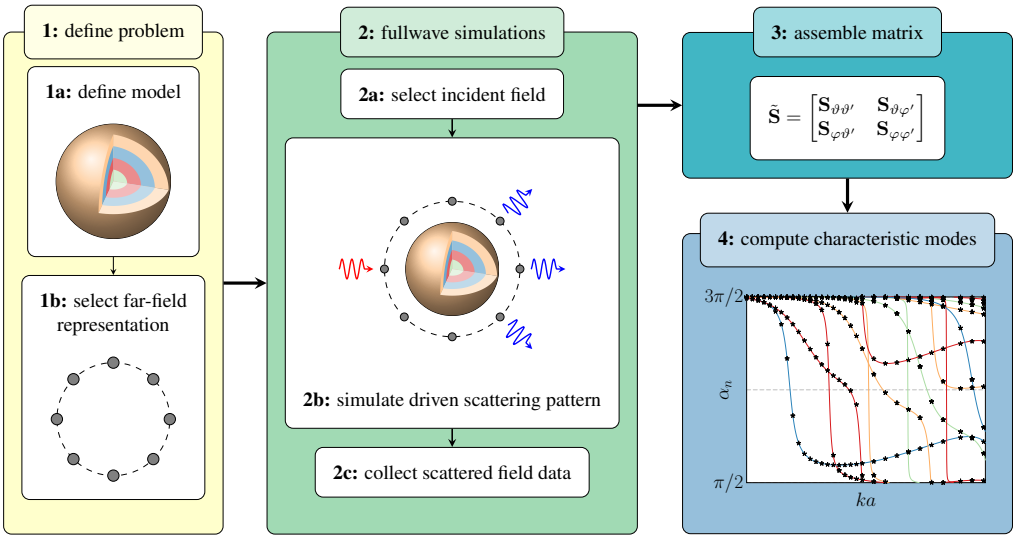


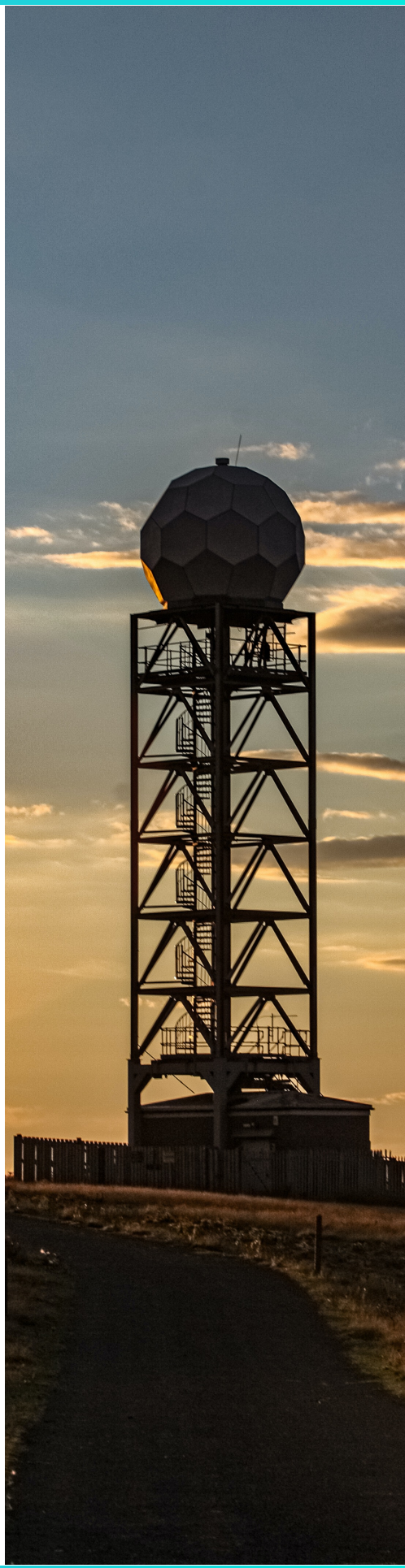
Figure 1: General procedure for computing scattering-based characteristic modes.

Source codes for replicating this example are given in the scattering dyadic method repository (linked above) under the `FEM_MoM-FEKO` subdirectory. To run this example, execute the script `Ex3B_*.m` (see the script for details on configuring communication between FEKO and MATLAB). The script first defines the model **(1a)** and the scattered field representation **(1b)**. The script then calls a generic routine `feko_sd.m`, which solves a series of scattering problems within FEKO **(2)** and constructs the scattering dyadic matrix from the resulting data **(3)**. From this matrix, the characteristic modes are computed and tracked using far-field correlation **(4)**. An optional script, `feko_cm.m` is available for plotting the characteristic field distributions.

1. M. Gustafsson, L. Jelinek, K. Schab, and M. Capek, "Unified Theory of Characteristic Modes - Part I: Fundamentals," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 12, pp. 11801–11813, Dec. 2022.
   General theoretical treatment of scattering-based characteristic modes using the transition matrix (spherical wave representation).
2. M. Gustafsson, L. Jelinek, K. Schab, and M. Capek, "Unified Theory of Characteristic Modes - Part II: Tracking, Losses, and FEM Evaluation," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 12, pp. 11814–11824, Dec. 2022.
   Discussion of specific technical aspects of non-MoM implementations of scattering-based CMA, including unique opportunities for simplified modal interpolation and tracking.
3. M. Capek, J. Lundgren, M. Gustafsson, K. Schab, and L. Jelinek,"Characteristic Mode Decomposition Using the Scattering Dyadic in Arbitrary Full-Wave Solvers," *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 1, pp. 830–839, Jan. 2023.
   General treatment of CMA based on the scattering dyadic (plane wave representation).
4. J. Lundgren, K. Schab, M. Capek, M. Gustafsson, and L. Jelinek, "Iterative Calculation of Characteristic Modes Using Arbitrary Full-Wave Solvers," *IEEE Antennas and Wireless Propagation Letters*, vol. 22, no. 4, pp. 799–803, Apr. 2023.
   An iterative method for accelerating scattering-based CMA in matrix-free methods, such as FEM, FDTD, and FMLMA.

News and Events

1. Inspired by the success of the 2018 Characteristic Modes Workshop organized by Prof. Yikai Chen (UESTC, China) on 17th July 2018 in Chengdu, China, we are organizing the second edition on 18th July 2023 in Beijing, China. Prof. Qi Wu (BUAA, China) is organizing the single-track event, and there is no registration fee. Please contact Qi Wu at qwu@buaa.edu.cn as soon as possible if you are interested to participate. The purpose of the workshop is for participants to present their latest results and exchange ideas.



2. The 2023 European Conference on Antennas and Propagation in Florence, Italy, was a great success! The CM-SIG was well represented at the conference with a convened CM session, other talks/posters, and our annual meeting. Big thanks (again) to Dave Bekers (TNO, The Netherlands) and Mahrukh Khan (The College of New Jersey (TCNJ), USA) for convening the CM session and also to Philipp Gentner (Ericsson, Germany) for stepping in to help chair the session. A photo taken after the annual meeting is included here.

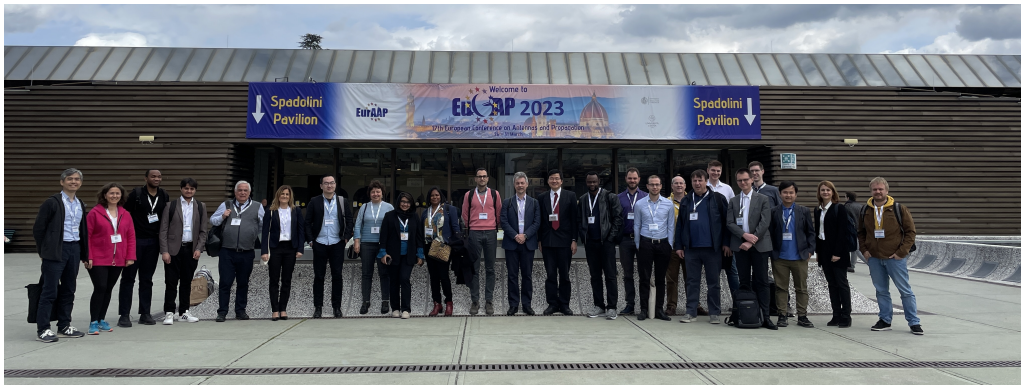


Figure 2: CM-SIG Group Meeting Photo taken at the EUCAP Conference on March 29, 2023.

3. The 2023 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (IEEE AP-S 2023) in Portland, USA (23-28 July 2023) will feature a good number of papers on characteristic modes reporting on latest results in the field (search for keywords!). In addition, Prof. Chao-Fu Wang (Temasek Laboratories, NUS, Singapore) will give a short course at IEEE AP-S 2023. Do not miss the opportunity to register for SC8: Theory of Characteristic Modes and Its Applications to the Analysis and Design of Antennas. Click here for details.

4. The CM-SIG will soon hold the 3rd edition of the European School of Antenna (ESoA) course on "Characteristic Modes: Theory and Applications" in Hannover, Germany. Prof. Dirk Manteuffel (Leibniz University Hannover, Germany) is the local organizer. The dates are 5-9 June 2023. More details can be found here.

Recent Articles on CM Theory

- M. Yazdani-Shavakand, J. Ahmadi-Shokouh, and H. Dashti, "A Fast Multi-Structural Tracking Method for Characteristic Modes with the Ability to Identify and Amend Errors," *IET Microwaves, Antennas & Propagation*, vol. 17, no. 1, pp. 62–74, Jan. 2023.
- Y. Dou and H. Chen, "Method of Characteristic Modes Analysis and Manipulation for Antenna Design by Using Generalized Partial Element Equivalent Circuit," *IEEE Journal on Multiscale and Multiphysics Computational Techniques*, vol. 8, pp. 123-134, Feb. 2023.
- X. Deng, D. Zhang, Y. Chen, and S. Yang, "Characteristic Mode Analysis: Application to Electromagnetic Radiation, Scattering, and Coupling Problems," *Chinese Journal of Electronics*, Feb. 2023.
- S. Huang, C. F. Wang, and M. C. Tang, "Generalized Surface-Integral-Equation-Based Sub-Structure Characteristic-Mode Solution to Composite Objects," *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 3, pp. 2626-2639, Mar. 2023.

Resources

Open Source Tools for CMA:

- FEKO-student edition
- CM MATLAB Software
- AToM Antenna Toolbox

Webinars:

- Our webinars on YouTube
- Our webinars on Bilibili
- Webinars from FEKO

Benchmarking Activity:

- Benchmarking in 2018

Available Courses:

- Courses offered by ESoA

Past Special Issues on CMA:

- July 2016 issue of IEEE Trans. Antennas Propag.
- April 2022 issue of IEEE Antennas Propag. Mag.

Past Issues of CM-SIG Newsletter:

- CM-SIG Newsletter

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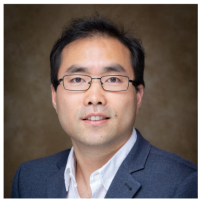


About CM-SIG: Characteristic Modes-Special Interest Group was initiated at the Special Session on CMs during the 2014, IEEE International Symposium on Antennas and Propagation in Memphis, TN, on 10 July 2014. CM-SIG was formed as a platform to promote technical activities in the field of CMs. For more information, please visit our website: http://www.characteristicmodes.org/.