Characteristic Modes Special Interest Group

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In This Issue:

Scholar Spotlight:

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Marco Leone is a Full Professor at Otto-von-Guericke University, Magdeburg, Germany. He has authored or co-authored more than 200 scientific journal and conference proceeding papers and has conducted numerous workshops regarding the EMC on the PCB level. He recently published the field-theory textbooks Theoretische Elektrotechnik (Springer) and Elektrische und Magnetische Felder (De Gruyter). His research interests include the EMC modeling and analysis of electronic systems.

Featured Article

An Accelerated Reduced-Order Characteristic Mode Analysis

by Hannes Schreiber, Philipp Herwigk, Marco Leone

Characteristic Mode Analysis (CMA) has become one of the most powerful tools for understanding and designing radiating and scattering structures. By decomposing a structure's current distribution into characteristic modes, CMA provides deep physical insight that guides antenna design, electromagnetic compatibility assessment and scattering analysis.

However, for broadband analyses, conventional CMA faces a serious bottleneck: each frequency point requires solving a large, frequency-dependent eigenvalue problem. For electrically large or complex geometries, this process becomes computationally prohibitive. Moreover, the mode-tracking problem—the need to correctly associate modes across frequencies—can lead to misidentified or lost modes when eigenvalue magnitudes reorder.

Our recent work introduces a highly efficient alternative that overcomes these limitations: the Accelerated Characteristic Mode Analysis (ACMA). The ACMA reformulates the CMA framework to obtain only the characteristic modes that are resonant in the considered bandwidth with only a fraction of the computational cost.

The key innovation behind ACMA is a basis change from the usual local basis functions to quasi-static modal current distributions, acting as global basis functions. Instead of repeatedly solving the full eigenvalue problem for each frequency, ACMA starts from a single, frequency-independent eigenvalue problem derived from the quasi-static inductance and capacitance matrices of the Method of Moments (MoM) system. The resulting quasi-static modes serve as a complete basis for constructing the full-wave current distribution. Using this basis, a modal full-wave system is established that is physically equivalent to the original MoM formulation. Within this system, two compact eigenvalue problems are formulated: one yields the inductive (solenoidal) modes, the other the capacitive (non-solenoidal) modes. It is shown that usually only a very small number of solenoidal and non-solenoidal modes are dominant in the bandwidth. The frequency response of all other modes can be approximated as purely quasi-static, so that the amplitudes of these modes are omitted as unknowns. This leads to two greatly reduced eigenvalue problems, each of which only provides the solenoidal and non-solenoidal modes that dominate in the bandwidth.

The ACMA reproduces the characteristic behavior of the conventional CMA but focuses on the dominant resonant modes within the considered bandwidth. The corresponding eigenvalues and eigenvectors show very good agreement with those obtained by the classical CMA. The ACMA eigenvectors can be interpreted as spectra of the CMA modes, indicating how the quasi-static basis modes combine to form the resonant full-wave modes. This spectral view also provides a new and efficient way to perform mode tracking: instead of tracking large current distributions directly, only their compact spectral representations need to be followed, making broadband analyses much more robust.

The proposed ACMA was validated using two representative examples. A perfectly conducting (PEC) spherical shell was analyzed from 1 MHz to 250 MHz. The ACMA recovered the analytical eigenvalues and eigenvectors of the dominant TE (inductive) and TM (capacitive) modes with very

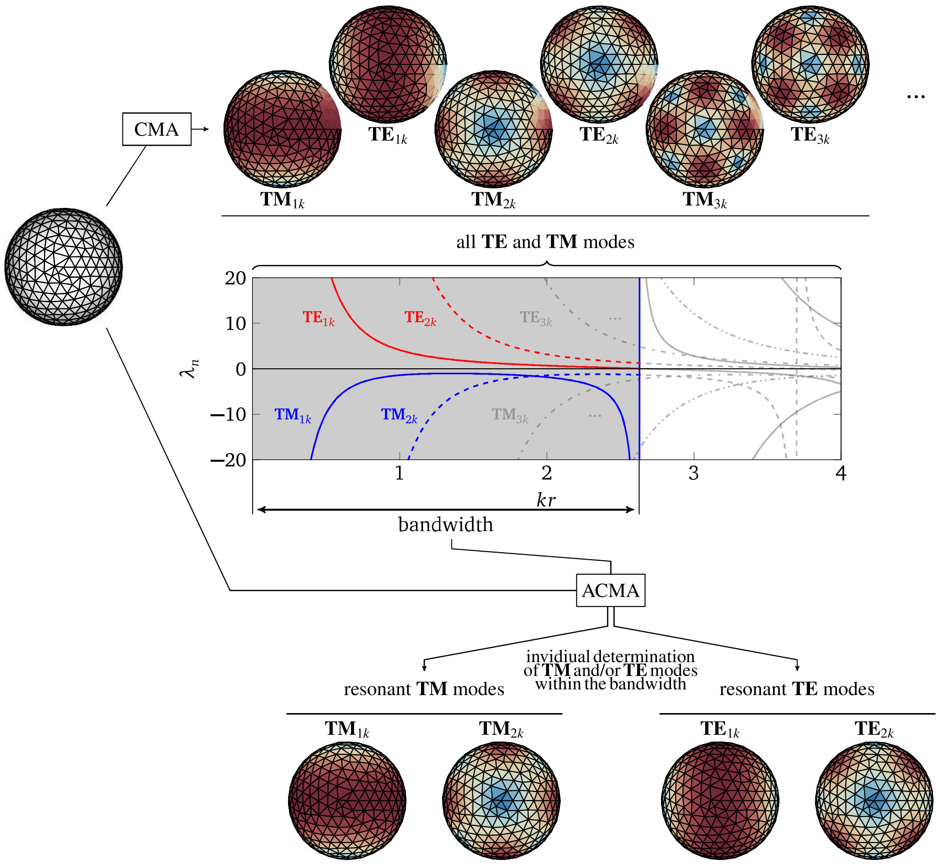
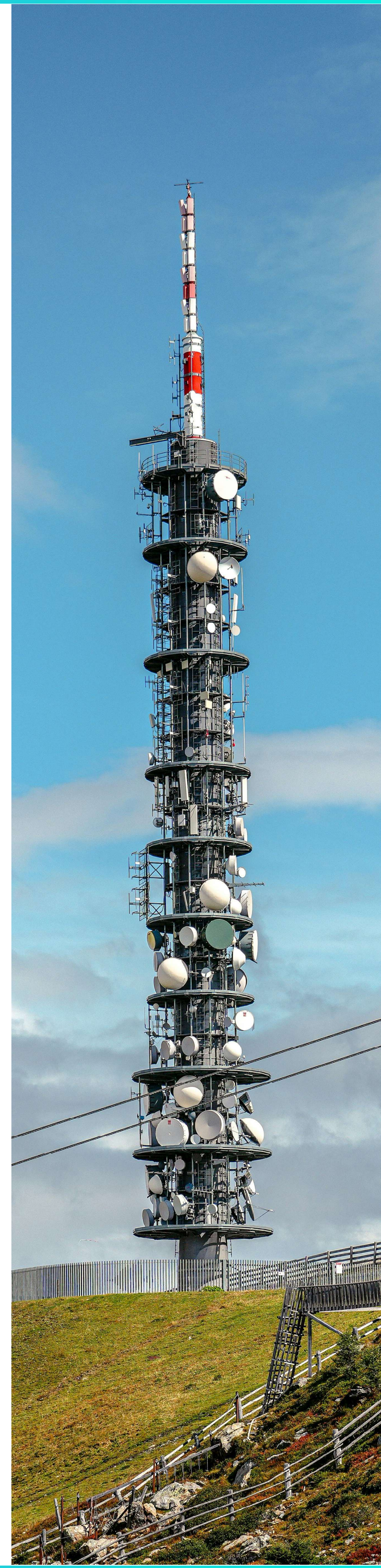


Figure 1: Visual comparison of the CMA and ACMA approach using the example of a PEC sphere.



good accuracy (see Fig. 1). The model order was reduced from 1128 to only 24—a 98% reduction—while maintaining nearly identical modal traces and current distributions within the frequency band of interest. A simplified drone model, composed of wire and surface elements, was analyzed between 1 MHz and 1 GHz. Here, the ACMA achieved the same dominant modal significances and characteristic currents as the conventional CMA, while eliminating mode-tracking errors entirely. Only 15 frequency samples were required, compared to hundreds for the classical approach, resulting in an overall reduction of computational effort by roughly 99.8%. Across both examples, the calculated characteristic currents achieved correlation factors above 0.97 with the CMA results, confirming the validity of the approximation.

The Accelerated Characteristic Mode Analysis demonstrates that CMA can be both physically meaningful and computationally lightweight. By replacing repeated frequency-dependent eigenvalue problems with a single quasi-static modal foundation, ACMA enables large-scale and broadband analyses that were previously impractical. Future extensions may integrate ACMA with hybrid numerical solvers such as FEM, or apply it to non-conducting and composite materials. Ultimately, the ACMA framework bridges the gap between physical modal insight and computational efficiency, making Characteristic Mode Analysis an even more powerful and accessible tool for modern electromagnetic design and analysis.

The complete derivations, application examples, and detailed discussions can be found in the full paper:

H. Schreiber, P. Herwigk and M. Leone, , “An Accelerated Reduced-Order Characteristic Mode Analysis”,in *IEEE Transactions on Antennas and Propagation*, vol. 73, no. 6, pp. 3827-3837, June 2025, doi: 10.1109/TAP.2025.3542620.

News and Events

1. Our proposal for a convened session on CMA at **EuCAP 2026 (19-24 April, Dublin, Ireland)** was accepted! The session title is "**Recent advances on theory and applications of characteristic modes in antenna modelling and design**" and the conveners are Li-Ying Nie (Hefei University of Technology, China) and Kurt Schab (Santa Clara University, USA).

Recent Articles on CM Theory

- D. Yang and Z. N. Chen, "Broadband Radiation Pattern Restoration of Self-Decoupled Metasurface Antenna by Balancing Common and Differential Modes," in IEEE Transactions on Antennas and Propagation, vol. 73, no. 10, pp. 7275-7283, Oct. 2025, doi: 10.1109/TAP.2025.3575942.
- Z. Ning, M. Li, L. Chen, J. Gu and D. Ding, "Circuit Modeling and Analysis of Multiband Energy-Selective Surfaces Using Characteristic Modes," in IEEE Transactions on Antennas and Propagation, vol. 73, no. 10, pp. 7583-7595, Oct. 2025, doi: 10.1109/TAP.2025.3575579.
- J. R. Lin et al., "Low-Profile Ultrawideband Vertically Polarized Patch Antenna Using Characteristic Mode Analysis," in IEEE Transactions on Antennas and Propagation, vol. 73, no. 10, pp. 7284-7291, Oct. 2025, doi: 10.1109/TAP.2025.3576591.
- B. Kim, S. Bang, S. Yun, H. Kim and J. Oh, "Broadband Holographic Mode Synthesis Between Adjacent Resonances for a Low-Profile Thin-Microstrip Antenna-Fed Metasurface," in IEEE Transactions on Antennas and Propagation, vol. 73, no. 11, pp. 9577-9582, Nov. 2025, doi: 10.1109/TAP.2025.3590571.
- J. Guo, M. Li, M. -C. Tang and R. W. Ziolkowski, "Differentially Fed, Self-Resonant, High-Efficiency, Superdirective Mixed-Multipole Antennas," in IEEE Transactions on Antennas and Propagation, vol. 73, no. 11, pp. 8740-8755, Nov. 2025, doi: 10.1109/TAP.2025.3598511.
- X. Fan, Y. Wang and F. Xu, "Dual-Band Dual-Polarized Stacked Gridded Patch Array With Wide-Angle Scanning Using Sidelobe Cancellation Technique for Smartphones," in IEEE Transactions on Antennas and Propagation, vol. 73, no. 11, pp. 8933-8945, Nov. 2025, doi: 10.1109/TAP.2025.3597663.
- W. Zhou, J. Gu, G. Cheng, D. Ding, Z. Huang and C. -F. Wang, "Fast Analysis of Electromagnetic Scattering From Large-Scale Quasi-Periodic Arrays Using the CMBF-EIM-AEGA Method," in IEEE Transactions on Antennas and Propagation, vol. 73, no. 11, pp. 9229-9241, Nov. 2025, doi: 10.1109/TAP.2025.3592818.
- M. H. M. Ardekani, A. Dastranj and S. Pashangeh, "Integration of Modified Degenerate Second-Order and Dominant Modes to Design a Broadband Single-Fed Circularly Polarized Patch Antenna," in IEEE Open Journal of Antennas and Propagation, vol. 6, no. 6, pp. 1787-1798, Dec. 2025, doi: 10.1109/OJAP.2025.3601195.
- B. Yang, J. Kim, T. Bellundagi and J. J. Adams, "Shape Synthesis and 3-D Ceramic Printing of Non-Canonical MIMO Dielectric Resonator Antennas," in IEEE Open Journal of Antennas and Propagation, vol. 6, no. 6, pp. 1763-1772, Dec. 2025, doi: 10.1109/OJAP.2025.3599763.
- H. Wu, C. Han, K. -Y. Jung, H. Kim, Y. Liu and L. Qu, "Dual-Band Co-Polarized MIMO Patch Antenna With Shared Aperture and High Isolation Using Charge Redistribution Stub," in IEEE Open Journal of Antennas and Propagation, vol. 6, no. 5, pp. 1300-1312, Oct. 2025, doi: 10.1109/OJAP.2025.3573596.

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

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/.