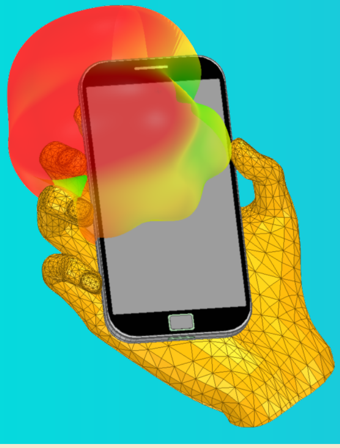


CM SIG

Characteristic Modes Special Interest Group

Newsletter, Volume 3, Number 3, Sep. 1st, 2023

In This Issue:

Scholar Spotlight:

Matti Kuosmanen received the M.Sc. (Tech.) degree in electrical engineering from Aalto University, Espoo, Finland, in 2021. Currently, he is pursuing a doctoral degree with Saab Finland Oy and the Department of Electronics and Nanoengineering, Aalto University. His research interests include wideband antenna arrays and the theory of characteristic modes.

Pasi Ylä-Oijala received the M.Sc. and Ph.D. degrees in applied mathematics from the University of Helsinki, Finland, in 1992 and 1999, respectively. Currently, he is a Staff Scientist with the Department of Electronics and Nanoengineering, Aalto University, Finland. His fields of interest include integral equation methods, theory and application of characteristic modes, and numerical modeling of complex electromagnetic material structures.

Contact (Authors):

matti.s.kuosmanen@aalto.fi
pasi.yla-oijala@aalto.fi

Featured Article

Characteristic Modes for Lossy Materials

by Matti Kuosmanen and Pasi Ylä-Oijala

The use of the method of moments (MoM) based characteristic modes (CMs) for lossless structures is a well-established way to design antennas and other radiating structures. However, in reality, all materials, including metals, dielectric, and magnetic materials, are lossy. Losses may cause a significant degradation in the antenna efficiency, and they should be taken into account in an early design phase. One approach is to include losses in the CM analysis such that the antenna designer can differentiate the efficient modes from the lossy ones. However, including losses in the CM analysis is not straightforward. In recent papers [1, 2, 3, 4], we have analyzed the limitations and opportunities of this technique.

Challenges of Losses

The first challenge associated with losses is the choice of the CM formulation. In the literature, several alternative ways to formulate the generalized eigenvalue equation (GEE) for lossy structures have been presented. In [1, 2, 4] we followed the *radiated power formulation* where the weight operator of the GEE is selected so that the eigenvalues are associated with the radiated power. This formulation leads to complex eigenvalues where the real part gives the ratio of reactive and radiated power and the imaginary part gives the ratio of dissipated and radiated power. The benefit of this formulation is that the dissipated power due to losses can be separated from the reactive power.

The second challenge is that the characteristic currents are typically not power orthogonal and the corresponding far fields are not Hermitian orthogonal if the structure is lossy. A consequence of this is that the power quantities associated with the CMs cannot be treated independently, and the power computed from the sum of modal currents does not agree with the sum of modal powers [1]. However, the modal currents are orthogonal also in the lossy case if the analyzed structure is sufficiently symmetric (e.g. a sphere) [1].

Despite losses breaking the far-field orthogonality, the impact of losses is usually small in dielectric materials and metals used in electromagnetic radiators. That is, the radiation and reactance parts of the MoM matrix dominate the eigenvalue problem, and the loss part does not significantly change the modal currents. In the next section, we demonstrate the effect of losses on the modal parameters.

Effect of Losses

We apply the CM analysis to a simplified, lossy model of a mobile phone antenna with a metal rim. A lossy metal is modeled with a surface impedance, $Z_s = (1-i)\sqrt{\omega\mu_0/(2\sigma)}$, where σ is the conductivity of the metal. The GEE is written for the electric field integral equation (EFIE) of an infinitesimal thin lossy metal plate [1, 3, 4]. As solutions of the GEE, we obtain a set of eigenvalues $\lambda_n, n = 1, 2, \ldots,$ and eigenvectors (eigencurrents).

Fig.1 demonstrates the effect of losses on the CMs by displaying their modal significance (MS), $1/|1-i\lambda_n|$, and modal efficiency (ME), $1/(1+\mathrm{Im}(\lambda_n))$, with corresponding eigencurrent distributions. The MS with losses describes the ratio of radiated power to apparent power, and ME, in turn, is the ratio of radiated power to active power.

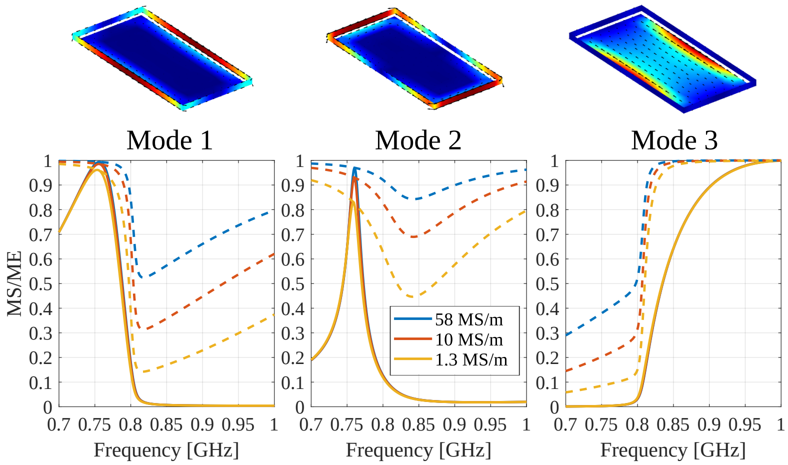


Figure 1: Currents of modes 1, 2, and 3 (from left to right), and their modal significances (solid line) and efficiencies (dashed line) versus frequency. Metal conductivity varies from 58 MS/m (copper) to 1.3 MS/m (high-quality silver paint) and illustrates the effect of the conductivity on the modal parameters.

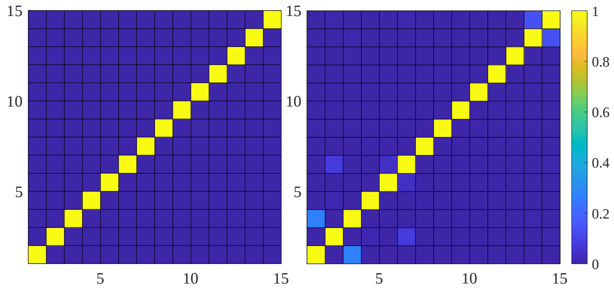


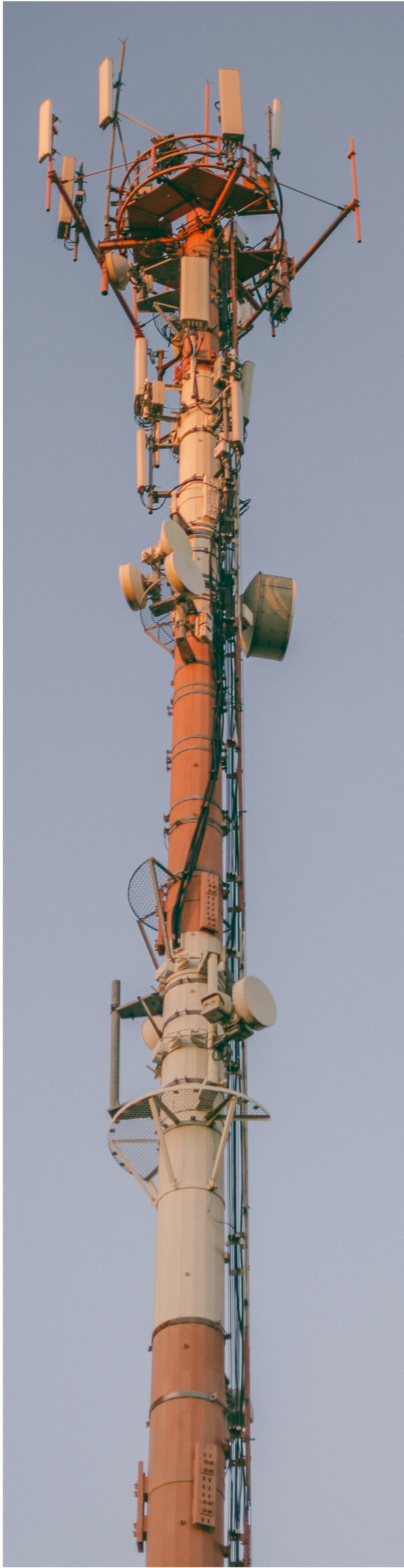
Figure 2: Power-orthogonality of CMs at 0.81 GHz when the antenna is made of lossless metal, i.e., PEC (left), and a lossy metal with conductivity of 1.3 MS/m (right). The axes give the mode index.

Looking at the results we observe that the MS and ME curves of modes 1 and 3 show a rapid change around 0.81 GHz. Mode 1 has good radiation below that frequency and mode 3 radiates most efficiently above it. We also note that losses seem to have the most significant impact on the MS of mode 2. Among the considered three modes, this mode has the narrowest frequency band. Consequently, narrow-band modes may be more sensitive to the losses than wide-band ones.

Figure 2 shows the normalized inner products of the eigencurrents of the first 15 modes, weighted with the radiation operator. Thus, they describe the orthogonality of the modal far fields. Evidently, the modes are perfectly orthogonal in the PEC case, whereas some modes (e.g., modes 1 and 3) are clearly correlated in the lossy case. The effect of non-orthogonality is frequency-dependent: it becomes prominent at the frequencies, where losses are significant but the modes have only a moderate amount of reactive energy, i.e. the loss part of the MoM matrix is significant in comparison with the reactance part.

News and Events

1. The International Workshop on Advances in Characteristic Mode Design and Analysis was successfully held at Beihang University, Beijing, China on 18 July 2023. There were around 40 participants and 12 experts that presented their work in the single-track event. The attendees were impressed with the quality and variety of the CM research topics presented. Qi Wu and his team also wowed the attendees with a technical tour of their huge experimental facility and very warm hospitality. The workshop was a follow-up of the 2018 Characteristic Modes Workshop organized by Yikai Chen (UESTC, China) on 17th July 2018 in Chengdu, China (interrupted by the COVID years), and we already have volunteers willing to host the next edition.



2. The CM-SIG successfully held the 3rd edition of the European School of Antenna (ESoA) course on ”Characteristic Modes: Theory and Applications” in Hannover, Germany from 5-9 June 2023. Big thanks to Dirk Manteuffel and his team from Leibniz University Hannover, Germany for their efforts as the local organizers. We were very pleased to have a group of very enthusiastic and motivated students from both academia and the industry. The next edition of the course is planned to be held in Lund, Sweden sometime in May or June of 2025.
3. Miloslav Čapek (Czech Technical University in Prague, Czech Republic) and Kurt Schab (Santa Clara University, USA) received the “2022 Edward E. Altshuler AP-S Magazine Prize Award” at the IEEE AP-S 2023 in Portland, USA (23-28 July 2023) for their paper “Computational Aspects of Characteristic Mode Decomposition: An Overview” IEEE Antennas and Propagation Magazine, vol. 64, no. 2, pp. 23-31, 2022. Congratulations!!! The paper is part of a 5-paper Special Issue (click here) organized by the CM-SIG surveying on the latest publications in the field.
4. Thanks to the efforts of Francesco Alessio Dicandia (CNR, Italy) and Kurt Schab (Santa Clara University, USA) in writing the proposal, as well as those who volunteer to present their latest work, there will be a CM convened session at the EuCAP 2024, Glasgow, 17-22 March 2023. We are expecting 5 papers to be presented at the session.
5. Altair FEKO has expanded the CMA feature for lossy dielectrics in their new release expected in September 2023. Additional details on this feature can be found on this LinkedIn post.

New Member Introduction

Bio: **Yong-Mei Pan** (M’11 - SM’17) received the B.Sc. and Ph.D. degrees in electronics engineering from the University of Science and Technology of China, Hefei, China, in 2004 and 2009, respectively. From 2009 to 2012, she was a Senior Research Assistant/Research Fellow with the Department of Electronic Engineering, City University of Hong Kong, Hong Kong, China. In 2013, she joined the School of Electronic and Information Engineering, South China University of Technology, Guangzhou, China, as an Associate Professor, where she is currently a Full Professor. Her research interests include dielectric resonator antennas, filtering antennas, MIMO antennas, and antenna-in-package. She is a Track Editor of the IEEE Transactions on Antennas and Propagation.

View on CMA: In my view, the theory of characteristic mode (TCM) is very powerful. It can perform modal analysis on arbitrary-shaped antenna structures to clearly provide its radiating and scattering properties, regardless of external excitation sources. Moreover, it can be widely applied in guiding antenna designs for bandwidth enhancement, mutual coupling reduction, radiation pattern synthesis, etc.

Summary of CMA Research:

1. We have investigated an advanced CM tracking method. The tracking method is based on the eigenvector correlation, and a novel tracking error correction algorithm is proposed to solve the challenging issues caused by the mode swapping and the mode degeneracy.
2. We have used TCM to aid the design of filtering patch antennas. Specifically, the TCM is used to help obtain the appropriate size of the radiator as well as the best feed position so as to excite the desired resonant modes and generate the inherent radiation nulls, providing clear physical insight into each design process.
3. We have developed a general self-decoupling method that utilizes the specific CMs of the ground plane with two or multiple parallel null-field regions for the MIMO antenna array. It has been shown that by properly exciting the CM using the excited antenna while simultaneously arranging the feed positions of the coupled antennas in the null-field regions, the mutual coupling between them can be decreased naturally and significantly.

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.

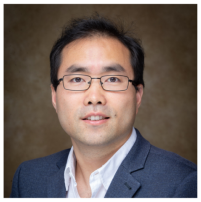
Past Issues of CM-SIG Newsletter:

- CM-SIG Newsletter

Contact Information (Editors):

Binbin Yang
Department of Electrical and Computer Engineering
North Carolina A&T State University
Greensboro, NC, USA 27411
byang1@ncat.edu

Kalyan Durbhakula
Missouri Institute for Defense and Energy
University of Missouri-Kansas City
Kansas City, MO, USA 64110
kalyandurbhakula@umkc.edu



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/.