Characteristic Modes Special Interest Group

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In This Issue:

Scholar Spotlight:

Shaode Huang received the B.S. degree in electromagnetic field and wireless technique and the Ph.D. degree in electromagnetic field and microwave technique from the University of Electronic Science and Technology of China, Chengdu, China, in 2014 and 2020, respectively. His research interests include computational electromagnetics and the theory of characteristic modes.

Chao-Fu Wang came to Singapore in 1999 to join the National University of Singapore and became a Principal Research Scientist in 2011. He has coauthored Characteristic Modes: Theory and Applications in Antenna Engineering. He was an Associate Editor of the IEEE Transactions on Microwave Theory and Techniques from 2020 to 2022.

Ming-Chun Tang received the Ph.D. degree in radio physics from the University of Electronic Science and Technology of China, Chengdu, China, in 2013. His research interests include electrically small antennas, RF circuits, and metamaterial designs and their applications.

Featured Article

Generalized Surface-Integral-Equation-Based Sub-Structure Characteristic-Mode Solution to Composite Objects

by S. Huang, C. -F. Wang and M. -C. Tang

The theory of characteristic modes (TCM) has been widely used in various antenna problems because it can provide the inherent modal behaviors of arbitrary electromagnetic objects [1]. In the framework of classical TCM, each part of the composite structures is almost equally important for the radiation/scattering of the structures. This characteristic is a double-edged sword for characteristic mode analysis (CMA), sometimes it aids in extracting all possible modal solutions, while at other times, it complicates the acquisition of desired resonant modes for antennas with platforms or loadings. Taking dielectric resonator antennas (DRAs) with a finite ground plane as an example, the major modes obtained from classical TCM are the resonant modes of the ground plane, not the dielectric resonator. However, one of the motivations for using DRAs is to reduce the conductor loss of metallic antennas in millimeter-wave systems. We aim to obtain the resonant modes of the dielectric resonator, not the ground plane. Therefore, classical TCM is unsuitable for analyzing practical DRAs with a finite ground plane. Similar issues are found in the CMA of microstrip patch antennas, Yagi-Uda antennas, wearable antennas, and so on.

As an extension of the classical TCM, the sub-structure characteristic modes (CMs) have shown some potential to solve this problem [2, 3, 4, 5]. In computing sub-structure CMs, the composite object is conveniently decomposed into two parts with different functions, the main radiator and passive loading. The distinctive feature of the sub-structure CMs is their ability to accurately capture the resonant modes that belong to the main radiator in the presence of passive loading. In this article, we propose a generalized surface integral equation (SIE)-based sub-structure CM formulation for composite objects. The evolution process of the proposed formulation is shown in Fig. 1.

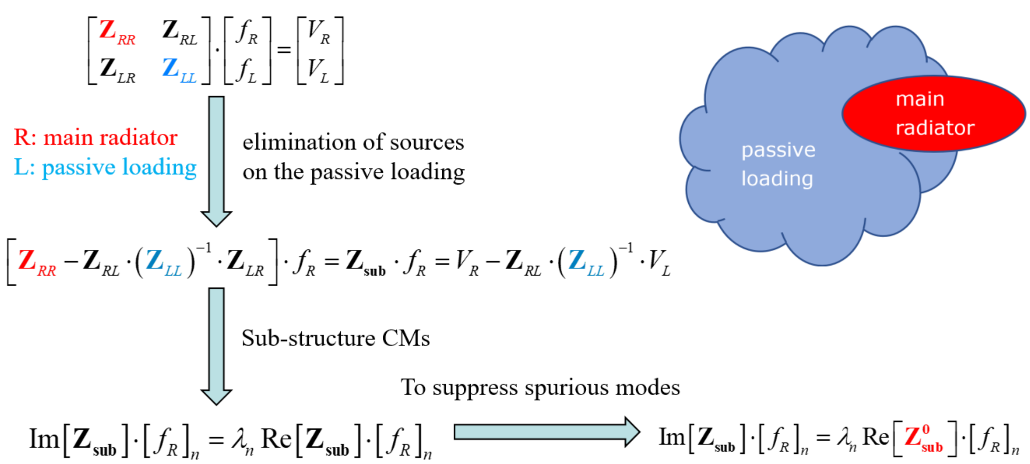
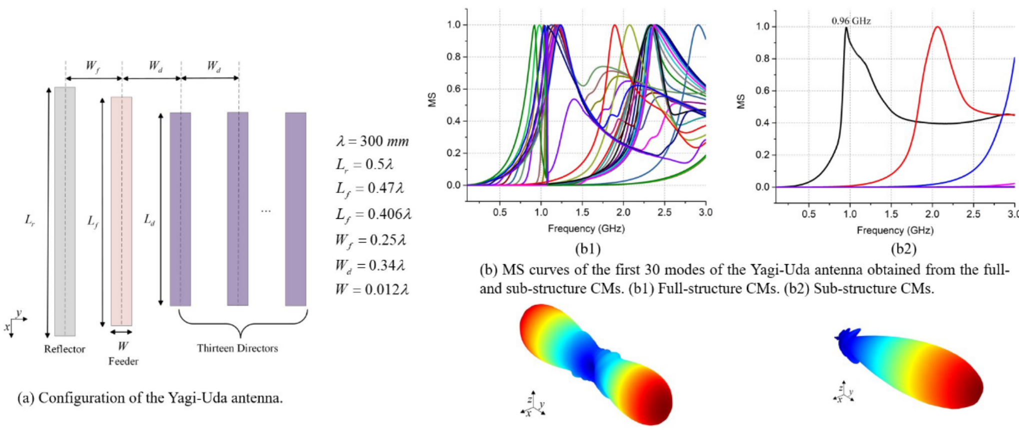


Figure 1: Evolution process of sub-structure CM formulation.



(a) Configuration of the Yagi-Uda antenna.
(b) MS curves of the first 30 modes of the Yagi-Uda antenna obtained from the full- and sub-structure CMs. (b1) Full-structure CMs. (b2) Sub-structure CMs.
(c). Radiation patterns of the dominant mode of the Yagi-Uda antenna obtained from the full- and sub-structure CMs. (c1) Full-structure CMs. (c2) Sub-structure CMs.

Figure 2: Full- and sub-structure CMs of a Yagi-Uda antenna.

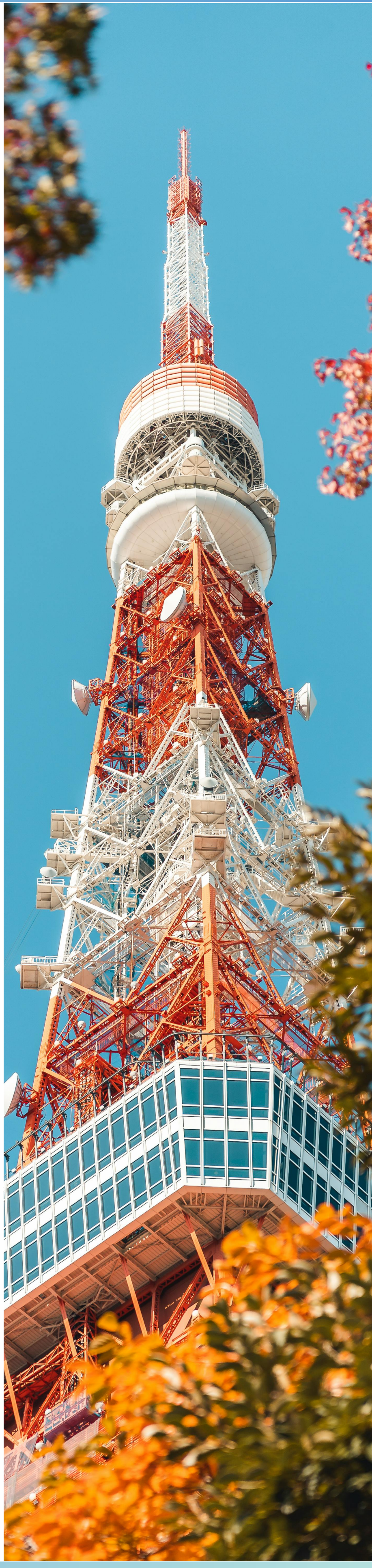
Based on the sub-structure CM formulation, we analyzed several practical antennas with localized excitations and platforms or loadings. Fig. 2 presents the full- and sub-structure CMs of a Yagi-Uda antenna. Our analysis reveals that sub-structure CMs can clearly identify the resonant frequency of the fundamental mode of the antenna. Furthermore, the radiation pattern of the sub-structure CMs aligns with the directional pattern of the Yagi-Uda antenna. This is because the sub-structure CMs consider the coupling effects between the main radiator and passive loading. For details, please refer to: 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, March 2023, DOI: 10.1109/TAP.2023.3237160.

News and Events

1. Our interest group continues to grow from strength to strength, as many as 8 new research groups/institutions joined us since the summer break this year. We are now 110 strong!
2. We welcome your ideas and input on possible new initiatives relating to the topic of characteristic mode analysis. Our past initiatives are listed here. For example, we have been actively supporting special session proposals at different workshops and conferences.
3. One of our members, Longyue Qu (Harbin Institute of Technology (Shenzhen), China) would like to invite you to submit a paper to their special session in RFAT 2024, called "Advanced MIMO Antenna Technology for 5G and Beyond". The session is co-organized with Hui Li (Dalian University of Technology, China) and Shuai Zhang (Aalborg University, Denmark). See the call for paper here. The paper submission deadline is 15 Dec 2024. For more information, feel free to contact Longyue Qu (rioinkorea@gmail.com).

Recent Articles on CM Theory

- P. Ylä-Oijala, M. Kuosmanen and H. Wallén, "Integral Operator-Based Characteristic Mode Theory for Conducting, Material, and Lossy Structures," *IEEE Transactions on Antennas and Propagation*, in press, doi: 10.1109/TAP.2023.3286039.
- R. Zhao, Y. Lu, G. S. Cheng, W. Zhu, J. Hu and H. Bagci, "Sub-structure Characteristic Mode Analysis of Microstrip Antennas Using a Global Multi-trace Formulation," *IEEE Transactions on Antennas and Propagation*, in press, doi: 10.1109/TAP.2023.3321437.
- H. Li, W. Zheng, Q. Wu and G. -L. Liu, "Pattern Synthesis for Lossy Antennas Based on N-Port Characteristic Mode Analysis," *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 6, pp. 4628-4639, June 2023, doi: 10.1109/TAP.2023.3256534.



- G. Shi et al., "Theoretic Study of Antenna Scattering Problems Based on Characteristic Modes and its Applications in Reducing Antenna Scattering," *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 3, pp. 2098-2109, March 2023, doi: 10.1109/TAP.2022.3229174.
- X. Guo, D. Kong, R. Lian, Y. Liu, and M. Xia, "A Study on Characteristic Mode Equations of Radiation Problems Contrasted with Scattering Problems for Dielectric Bodies," *Electronics*, vol.12, no.3, Jan. 2023, https://doi.org/10.3390/electronics12030704.
- Zhong-Gen Wang, F. Guo, W-Y. Nie, Y. Sun, and P. Wang, "Principal Component Analysis Accelerated the Iterative Convergence of the Characteristic Mode Basis Function Method for Analyzing Electromagnetic Scattering Problems," *Progress In Electromagnetics Research M*, vol. 117, pp. 129-138, 2023.

New Member Introduction

Bio: **Xing-Yue Guo** (M'21) received the B.S. degree in electronic information science and technology from Southwest Jiaotong University, Chengdu, China, in 2011, and the M.E. degree in electronic and communication engineering from the University of Electronic Science and Technology of China, Chengdu, China, in 2014, and the Ph.D. degree in electromagnetic field and microwave technology from Peking University, Beijing, China, in 2021. She is currently a Distinguished Associate Research Fellow with the Beijing University of Posts and Telecommunications, Beijing, China. Her research interests include the theory of characteristic mode, computational electromagnetics, and applications.

View on CMA: The theory of characteristic mode (TCM) has become a promising tool for antenna analyses and designs in recent years. In my view, the existing TCM formulations are not sufficient to meet the requirements of real engineering applications. There exist some open issues to be addressed, especially for TCM based on surface integral equations for metal-dielectric structures. I want to clarify the underlying physical mechanism of why the spurious modes are prone to be generated for lossy dielectric problems, as well as develop the appropriate characteristic mode formulations for both scattering and radiation problems.

Summary of CMA Research:

1. In 2017, TCM based on surface integral equations (SIE) for the lossy dielectric bodies had not been addressed. Some researchers pointed out that the main difficulty behind this was the separation of dissipation power from the total active power for the lossy dielectric bodies. For this reason, we proposed the characteristic mode formulations based on the explicit separation of dissipation power from the total active power, and employed a single effective electric or magnetic current instead of traditional electric and magnetic currents in order to avoid the inverse operation of ill-conditioned matrix.
2. The SIE-based TCM can be classified into two types: i) giving real characteristic eigenvalues but non-orthogonal far field pattern, ii) giving complex characteristic eigenvalues but orthogonal far field pattern approximately. There exist extra modes for the lossy dielectric bodies by using the first type of SIE-based TCM formulations. In order to suppress the spurious and extra modes, we proposed several variant characteristic mode formulations by using different dissipation power operators for lossy dielectric bodies.
3. In order to clarify the underlying reason why the spurious modes are prone to be generated by using traditional PMCHWT-based TCM, we demonstrated that the impedance matrix of the PMCHWT equation could not distinguish (i) which domain is the dielectric body and which domain is the background and (ii) from which domain the excitation source was applied. We thought that the TCM formulations for radiation and scattering problems should be addressed independently.

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/.