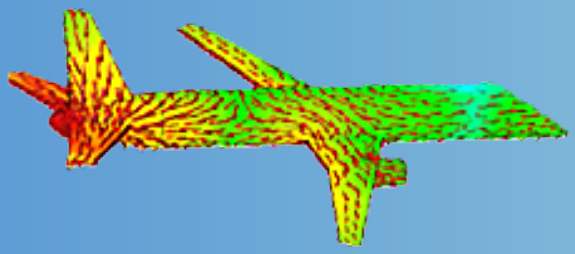


Characteristic Modes Special Interest Group

Newsletter, Volume 4, Number 1, 1st Mar. 2024

In This Issue:

Scholar Spotlight:

Ruyu Ma received the B.Sc. and M.Sc. degrees in electrical engineering from the Harbin Institute of Technology, Harbin, China, in 2013 and 2015, respectively, and the Ph.D. degree in electrical engineering from the University of Wisconsin-Madison, Madison, WI, USA, in 2020. Currently, he is a Research Associate with the University of Wisconsin-Madison. His research interests include direction-of-arrival estimation, electrically-small antennas, platform-based antennas, and millimeter-wave radar systems.

Nader Behdad received the B.S. degree in electrical engineering from the Sharif University of Technology, Tehran, Iran, in 2000, and the M.S. and Ph.D. degrees in electrical engineering from the University of Michigan, Ann Arbor, USA, in 2003 and 2006, respectively. He is currently the McFarland-Bascom Professor with the Department of Electrical and Computer Engineering, University of Wisconsin-Madison, Madison, USA. His research interests include applied electromagnetics with a particular focus on electrically small antennas, phased array antennas, bio-electromagnetics, microwave ablation, microwave periodic structures, and high-power microwaves.

Featured Article

A Spatially Confined, Platform-Based HF Direction Finding Array

by R. Ma and N. Behdad

This work concerns a spatially-confined, high-frequency (HF) antenna array with enhanced bandwidth and direction finding (DF) accuracy suitable for installation on a mobile platform and using the presence of the platform to achieve performance enhancement. The HF band is in the frequency range of 3 to 30 MHz, corresponding to wavelength of 10 to 100 m. This band is widely used in many important civilian and military applications, such as over-the-horizon radar systems, aviation/maritime communications and services, beyond line of sight (BLOS) communications, shortwave international and regional broadcasting and Global Maritime Distress and Safety System (GMDSS) communication, among others. As a result, HF DF systems are of great interest in military communications and electronic warfare support applications among other civilian applications.

However, due to the large wavelength in the HF band, practical DF arrays mounted on mobile platforms tend to be electrically small, resulting in fundamental limitations on antenna bandwidth and DF accuracy. The authors cited many articles that have been published on the physical limitations on the performances of electrically small antennas and designs that approach these limitations. Among them, one paper reports an upper bound of DF accuracy of electrically small antenna arrays, which is set by the dimensions of the aperture. While the authors cited some articles that, to surpass this limitation, employ the presence of a relatively large platform nearby the antenna to achieve enhanced DF accuracy and bandwidth, these approaches either result in a large array aperture or need to make significant changes to the platform. For example, in the authors' previous work, electrically-small antenna elements are installed on multiple locations of an airplane to efficiently excite and use the platform's characteristic modes (CMs) for much-enhanced DF accur-

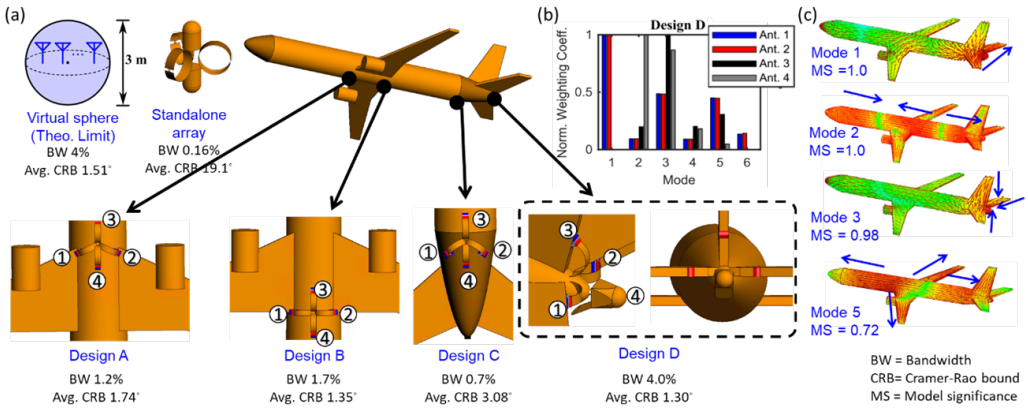


Figure 1: (a) Bandwidth, averaged Cramer-Rao bound, and illustrative pictures of the proposed Designs A-D, a standalone array occupying the same volume and a virtual sphere that can contain design. (b) Normalized weighting coefficients and (c) the current distribution of the significant characteristic modes (CM) excited by the Design D, demonstrating diverse CM and current excitation of different antennas.

acy and bandwidth. Each antenna is small but the antennas are placed at designated and largely-separated locations, making the array aperture much larger than any antenna element. This, however, may have difficulties in practical applications, as many applications require mounting the array at a single location on the platform due to limited space and mobility considerations.

To alleviate these issues, the authors employ the platform as the major radiator by exciting several of its significant characteristic modes (CMs) using a spatially confined antenna array. Averaged Cramer-Rao bound (CRB) is used as a figure of merit to evaluate the DF performance. CRB is a lower error bound of an unbiased estimator. This array can achieve a better average CRB compared with the lowest CRB theoretically achievable from any standalone antenna array occupying the same volume.

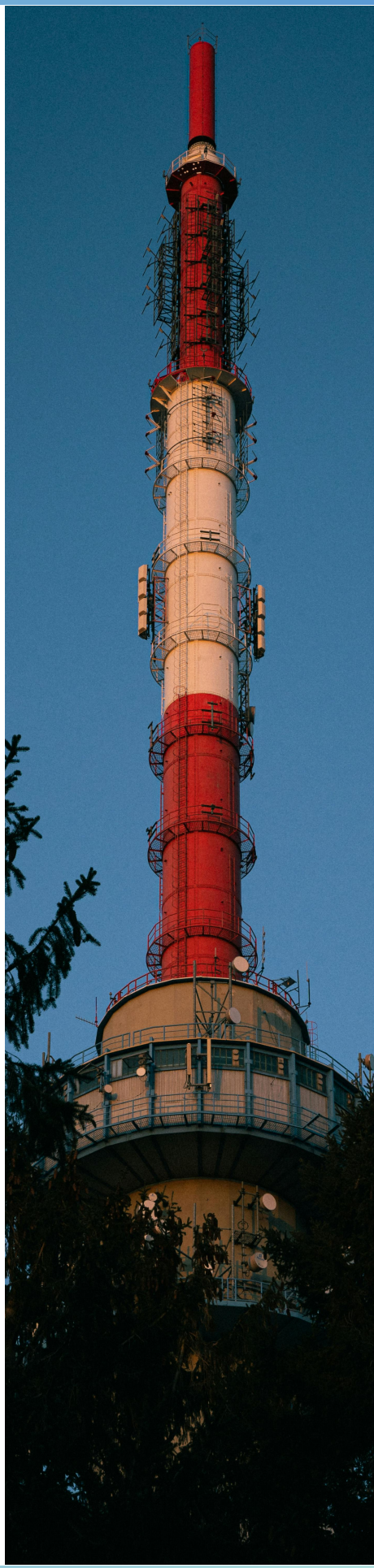
Specifically, the authors examined four DF array designs mounted on a representative, mid-size passenger airplane operating at 10 MHz in simulation. Each design is confined within a virtual sphere with a 3 m diameter. The location of the spatially confined array is first determined by selecting the locations where multiple significant CMs have strong surface currents or high charge densities. This is the location where antennas can couple to multiple CMs more strongly. Subsequently, the antenna elements of the array are designed to effectively excite these CMs. As the coupling elements are electrically small, they can be either capacitive or inductive coupling element (CCE/ICE). Finally, the design with lowest averaged CRB was selected for further investigation. The design was also demonstrated to have the most diverse weighting coefficients of the excited CMs. For details, please refer to: R. Ma and N. Behdad, "A Spatially Confined, Platform-Based HF Direction Finding Array," IEEE Transactions on Antennas and Propagation, vol. 70, no. 2, pp. 1298-1308, Feb. 2022, DOI: 10.1109/TAP.2021.3111311.

News and Events

1. We are expecting quite some activities in characteristic modes (CMs) at the 2024 European Conference on Antennas and Propagation (EuCAP 2024), Glasgow, 17-22 March 2024:
   - The Convened Session "CS18: Characteristic Modes Analysis for Next-Generation Wireless Technologies", organized by Francesco Alessio Dicandia (CNR, Italy) and Kurt Schab (Santa Clara University, USA), is currently scheduled for Tue, 19 March 2024, 8.30-10.10 (Room M4).
   - More than 20 CM papers will be presented in both oral and poster sessions of EuCAP 2024.
   - We will hold our annual CM-SIG meeting there, currently scheduled for 13.30-14.30 on Wed, 20 March 2024 in the meeting room Fyne. The meeting can also be found in the conference program, but note that the start time is 13.30, not 13.10.
2. There will be at least one focused session on characteristic modes at the 2024 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (IEEE AP-S 2024) in Florence, Italy (14-19 July 2024). The conference received a remarkable 2045 paper submissions, a significant 34% increase compared to the last three editions, and hitting the historical record of all IEEE AP-S/URSI Symposia.

Recent Articles on CM Theory

- C. Guo, Y. -C. Jiao and Y. Ren, "An Alternative Surface-Integral-Equation-Based Sub-Structure Characteristic Mode Formulation for Lossy Composite Structures," *IEEE Transactions on Antennas and Propagation*, vol. 72, no. 1, pp. 707-719, Jan. 2024, doi: 10.1109/TAP.2023.3332477.
- M. Capek and L. Jelinek, "The Upper Bound on Antenna Gain and Its Feasibility as a Sum of Characteristic Gains," *IEEE Transactions on Antennas and Propagation*, vol. 72, no. 1, pp. 277-289, Jan. 2024, doi: 10.1109/TAP.2023.3323763.
- K. Schab, F. W. Chen, L. Jelinek, M. Capek, J. Lundgren and M. Gustafsson, "Characteristic Modes of Frequency-Selective Surfaces and Metasurfaces From S-Parameter Data," *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 12, pp. 9696-9706, Dec. 2023, doi: 10.1109/TAP.2023.3324991.



- H. Li, Y. Diao, J. Yu and X. Zhang, "Time-Efficient Method for Designing Uncorrelated Platform-Integrated MIMO Antennas," *IEEE Antennas and Wireless Propagation Letters*, vol. 22, no. 12, pp. 2846-2850, Dec. 2023, doi: 10.1109/LAWP.2023.3301012.
- W. Zheng, Y. Pan and H. Li, "Synthesis of Filtering Terminal Antennas Based on N-Port Networks," *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 10, pp. 8278-8283, Oct. 2023, doi: 10.1109/TAP.2023.3296806.
- Y. Kuang, Q. S. Cheng and Z. N. Chen, "Characteristic Mode-Guided Trust-Region-Based Optimization for Mode Manipulation in Dual-Band Metantenna Design," *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 12, pp. 9717-9727, Dec. 2023, doi: 10.1109/TAP.2023.3317982.
- J. -F. Lin and L. Zhu, "A Novel Characteristic Mode Method to Enhance Axial-Ratio Bandwidth of Low-Profile Circularly Polarized Planar Antennas," *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 12, pp. 9365-9374, Dec. 2023, doi: 10.1109/TAP.2023.3328138.

New Member Introduction

Bio:Jiang-Feng Lin (S'16-M'18) was born in Shantou, Guangdong, China, in 1991. He received the B.S. degree in communication engineering from the Beijing University of Posts and Telecommunications (BUPT), Beijing, China, in 2013, and the Ph.D. degree in electronic engineering from the South China University of Technology (SCUT), Guangzhou, China, in 2018. From 2019 to 2022, he was the Post-Doctoral Research Fellow under the UM Macao Talent Program with University of Macau (UM), Macau, China. He is currently an Associate Professor with South China Normal University (SCNU), Guangzhou, China. His research interests include characteristic mode theory, high-gain and/or wideband antennas, dual-beam antennas, MIMO antennas, and antenna decoupling.

View on CMA: Many modal theories have been proposed and applied to analyze and design microwave devices. However, most of them focus on regular-shaped and nonradiating structures, hardly referring to irregular-shaped or radiating ones. CMA resolves this issue and has the ability to provide physical insights into arbitrary-shaped radiating structures. Moreover, CMA can arouse systematic methods for efficient antenna design, getting rid of the prevalent and time-consuming cut-and-try process.

Summary of CMA Research: In the past few years, we have devoted ourselves to designing various antennas with new systematic methods. One can get the design process efficiently done by following these methods, rather than relying solely on clumsy simulations without specific procedures.

1. Characteristic modes are elaborately manipulated and controlled in resonance, polarization, and directivity. In such way, low-profile circularly-polarized antennas with enhanced axial-ratio bandwidth or high gain are successfully achieved.
2. A general equivalent circuit in transversal topology is created with CMA for various multi-port antennas. This general circuit can guide the MIMO antenna design in order to realize port decoupling and impedance matching at the same time.
3. Antenna coupling is analyzed and studied comprehensively with CMA. Then we leverage antenna coupling to attain wide bandwidth, circular polarization, and dual-beam radiation by taking advantage of the even/odd modes or c/π modes.

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/.