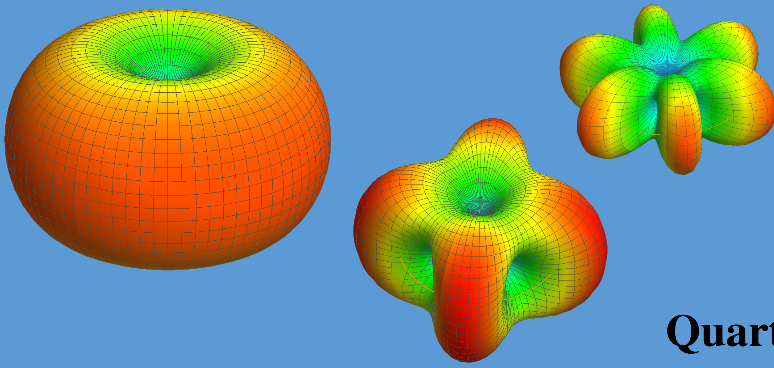

Characteristic Modes Special Interest Group

Quarterly Newsletter, Number 1, June 1, 2021

In This Issue:

Scholar Spotlight:

Nikolai Peitzmeier was born in Luebbecke, Germany, in 1988. He received the B.Sc. and M.Sc. degrees in electrical engineering and information technology from the Leibniz University Hannover, Germany, in 2013 and 2014, respectively. Since then, he has been a Research Assistant with the Institute of Microwave and Wireless Systems, Leibniz University Hannover. His current research is focused on antenna design for MIMO applications, including beamforming and massive MIMO, based on the theory of characteristic modes in conjunction with the theory of symmetry. Further fields of interest are electromagnetic theory and simulation techniques.

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Featured Article

"Upper Bounds for Uncorrelated Ports on Multimode Antennas Based on Symmetry Analysis of Characteristic Modes", *by Nikolai Peitzmeier*

Multimode antennas are a promising, space-efficient alternative to multi-antenna architectures for MIMO systems. In contrast to conventional antenna arrays whose elements are located spatially apart to provide spatial diversity, multimode antennas consist of a single element with independent ports offering pattern diversity.

Over the past decade, characteristic modes have been used extensively for the design of multimode antennas. This design approach is enabled by the orthogonality of the characteristic far fields. The aim is to selectively excite different modes by suitable ports. If separate ports excite different modes, respectively, these ports are perfectly uncorrelated, which is most beneficial for MIMO performance.

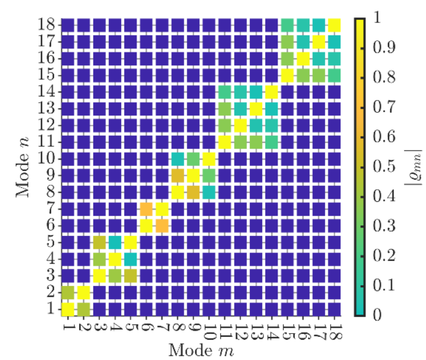

Figure 1: Characteristic current correlation coefficients of square plate with electrical size $ka = 4$. The first 18 modes are taken into account and sorted into mutually exclusive sets. Dark blue is equal to zero.

Unfortunately, it is generally not possible to excite a single mode independently of other modes. This is due to the fact that the characteristic current densities are not guaranteed to be directly orthogonal to each other (in contrast to the characteristic far fields). They are only orthogonal with respect to the impedance operator. Consequently, a port that is supposed to excite a certain mode will also excite those modes whose current densities are correlated, limiting the degrees of freedom for realizing uncorrelated ports.

In Fig. 1, the correlation of the characteristic current densities of a square plate is shown. It is found that there are exactly six mutually orthogonal sets of characteristic current densities, regardless of how many modes are considered. For example, modes 1 and 2 form one such set. Their current densities are correlated, but are orthogonal to those of the other modes. This set may thus be excited independently of the other sets.

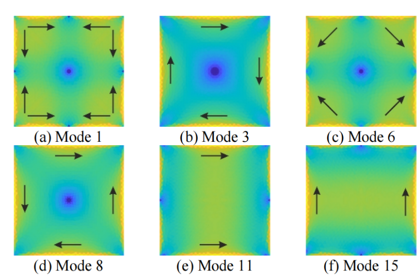

Figure 2: Selected characteristic current densities of square plate with electrical size $ka = 4$.

For each set, one representative characteristic current density is listed in Fig. 2. These current densities have different symmetry properties. For example, mode 1 is invariant under all symmetry operations of the square plate, whereas modes 3, 6, and 8, respectively, are only invariant under certain operations, but inverted by others. The degenerate modes 11 and 15 may even transform into each other. These transformations are expressed by the so-called irreducible representations of the symmetry group of the square plate. As a matter of fact, the irreducible representations arise naturally in conjunction with characteristic modes. The characteristic current densities act as basis functions of the irreducible representations. Each current density can thus be assigned to exactly one irreducible representation, yielding mutually orthogonal sets. Current densities belonging to the same set have the same symmetry properties and are correlated (cf. Fig. 1).

Due to this fundamental connection between the symmetry of an antenna and its characteristic modes, only symmetric antennas offer mutually orthogonal sets of characteristic current densities, and only these sets can be excited separately. However, the number of these sets is limited by the antenna symmetry, regardless of the number of modes taken into account. Hence, there is an upper bound for uncorrelated ports which stems from the finite number of the irreducible representations and is thus directly dictated by the symmetry. The higher the symmetry order of an antenna, the more uncorrelated ports can be realized.

This symmetry analysis is generally valid and can be applied to any antenna geometry. For details, please refer to: N. Peitzmeier and D. Manteuffel, "Upper bounds and design guidelines for realizing uncorrelated ports on multimode antennas based on symmetry analysis of characteristic modes," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 6, pp. 3902–3914, 2019, doi: 10.1109/TAP.2019.2905718.

CM News and Events

1. The Second Edition of the European School of Antenna (ESoA) Course on "Characteristic Modes: Theory and Applications" was successfully held online during 24-28 May 2021. The course is jointly organized by Czech Technical University in Prague, Universitat Politecnica de Valencia, Leibniz Universität Hannover and Lund University. A good number of students attended and the interactions were better than expected for an online course. Many thanks to the organizers (Pavel Hazdra and Miguel Ferrando Bataller) for making it happen!
2. Two CM SIG webinars were held on 15th April 2021. Check them out here.
3. The convened Session "Characteristic Mode Analysis for Emerging Applications and New Structures" was held at the 2021 European Conference on Antennas and Propagation, 22-26 March, 2021 (Organizers: Dirk Manteuffel, Kalyan C. Durbhakula, and Fenghan Lin)

Recent Articles on CMA (First Quarter of 2021)

- L. Zhang et al., "A Quad-Polarization Reconfigurable Antenna With Suppressed Cross Polarization Based on Characteristic Mode Theory," in *IEEE Trans. Antennas Propag.*, vol. 69, no. 2, pp. 636-647, Feb. 2021, doi: 10.1109/TAP.2020.3016384.
- J. -F. Lin and L. Zhu, "Low-Profile High-Directivity Circularly-Polarized Differential-Fed Patch Antenna With Characteristic Modes Analysis," in *IEEE Trans. Antennas Propag.*, vol. 69, no. 2, pp. 723-733, Feb. 2021, doi: 10.1109/TAP.2020.3016465.
- P. Ylä-Oijala and H. Wallén, "Theory of Characteristic Modes for Non-symmetric Surface Integral Operators," in *IEEE Trans. Antennas Propag.*, vol. 69, no. 3, pp. 1505-1512, March 2021, doi: 10.1109/TAP.2020.3017437.
- A. Narbudowicz R. Borowiec and S. Chalermwisutkul, "No-Need-To-Deploy UHF Antenna for CubeSat: Design Based on Characteristic Modes," in *IEEE Antennas Wireless Propag. Lett.*, vol. 20, no. 4, pp. 508-512, April 2021, doi: 10.1109/LAWP.2021.3055418.
- S. Cao, Z. Zhang, X. Fu and J. Wang, "Pattern-Reconfigurable Bidirectional Antenna Design Using the Characteristic Mode Analysis," in *IEEE Antennas Wireless Propag. Lett.*, vol. 20, no. 1, pp. 53-57, Jan. 2021, doi: 10.1109/LAWP.2020.3039506.
- H. Sheng and Z. N. Chen, "Improving Radiation Pattern Roundness of a Monopole Antenna Placed Off-Center Above a Circular Ground Plane Using Characteristic Mode Analysis," in *IEEE Trans. Antennas Propag.*, vol. 69, no. 2, pp. 1135-1139, Feb. 2021, doi: 10.1109/TAP.2020.3004991.
- X. Gao, G. Tian, Z. Shou and S. Li, "A Low-Profile Broadband Circularly Polarized Patch Antenna Based on Characteristic Mode Analysis," in *IEEE Antennas Wireless Propag. Lett.*, vol. 20, no. 2, pp. 214-218, Feb. 2021, doi: 10.1109/LAWP.2020.3044320.

Resources

Open Source Tools for CM Analysis:

- FEKO-student edition
- CM Matlab Software
- Antenna Toolbox for Matlab (Atom)

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 CM:

- Special issue on TCM in the July 2016 issue of IEEE transactions on Antennas and Propagation.

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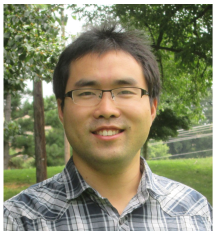

About CM-SIG: Characteristic Modes-Special Interest Group was initiated at the Special Session on CMs during the 2014, IEEE International Symposium on Antennas and Propagation in Memphis, TN, on 10 July 2014. CM-SIG was formed as a platform to promote technical activities in the field of CMs. For more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