

Characteristic Mode Guided Design Framework for Electromagnetic Structures

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Theory of characteristic modes (TCM) or characteristic modes (CM) theory has been used to analyze and design many electromagnetic (EM) structures, such as different types of antennas, meta surfaces, frequency selective surfaces and so on. As reported by many publications, TCM is useful to intuitively understand EM modal behavior of the structures being analyzed, like their eigenvalue, resonant frequencies, modal currents, and modal fields (Y. Chen and C. F. Wang, *Characteristic Modes: Theory and Applications in Antenna Engineering*. Hoboken, NJ, USA: Wiley, 2015). All these modal solution variables/components are helpful to guide to achieve design goals of the EM structures through observing the EM physics of some of the modal solution components (D. Zha et al., “A physical insight into reconfigurable frequency selective surface using characteristic mode analysis,” *IEEE Antennas Wireless Propag. Lett.*, vol. 20, no. 10, pp. 1863–1867, Oct. 2021; T. Li et al., “Characteristic modes-inspired polarization twisting metasurface element for 1-bit folded reflectarray,” *IEEE Antennas Wireless Propag. Lett.*, vol. 21, no. 11, pp. 2254–2258, Nov. 2022). However, how to physically link the modal solution components to the required design goal/performance parameters has not been fully explored yet.

This paper tries to explore how to apply the modal solution components of TCM to physically connect to the design parameters of the EM structures and produce the designed structures with expected performance. To achieve this goal, a general liner operator equation will be used to describe the EM problem related to the EM structures (C. F. Wang, “Unified view of surface integral equation based sub-structure characteristic mode analysis methods,” *IEEE International Symposium on Antennas and Propagation*, pp. 1837-1838, July 2328, 2023, Portland, Oregon, USA). With this general liner operator equation, we will develop a general sub-structure CM theory that will cover conventional full structure CM theory (S. Huang, C. F. Wang, and M. C. Tang, “Generalized surface integral equation-based substructure characteristic mode solution to composite objects,” *IEEE Trans. Antennas Propag.*, vol. 71, no. 3, pp. 2626-2639, Mar. 2023). This sub-structure CM theory will be used to obtain modal solution components for different EM structures. With clear EM physics, these modal solution components can be connected with EM performance parameters that can be iteratively improved to achieve final design goal of performance. This strategy has been partially implemented to successfully realize the design of broadband tunable microwave metasurface absorbers and reconfigurable frequency-selective surfaces validated with prototype and experiment results (Z. H. Ning, M. Li, D. Z. Ding, X. Ai, J. Q. Liu, and C. F. Wang, “A step-bystep design methodology for broadband tunable microwave metasurface absorbers using theory of characteristic modes,” *IEEE Open J. Antennas Propag.*, vol. 5, no. 4, pp. 899–912, Aug. 2024; Z. H. Ning, M. Li, J. Gu, D. Ding, and C. F. Wang, “Characteristic mode-based resonance model for analyzing and designing reconfigurable frequency-selective surfaces,” *IEEE Trans. Electromagn. Compat.* (Early Access), DOI: 10.1109/TEM.2024.3486544, 11 November 2024).