Post-processing removal of non-real characteristic modes via basis function perturbation

Miers, Zachary; Lau, Buon Kiong

Published in:
2016 IEEE International Symposium on Antennas and Propagation (APSURSI)

DOI:
10.1109/APS.2016.7695918

2016

Document Version:
Peer reviewed version (aka post-print)

Post-processing Removal of Non-real Characteristic Modes Via Basis Function Perturbation

Zachary Miers and Buon Kiong Lau
Department of Electrical and Information Technology
Lund University
22363 Lund, Sweden
Zachary.Miers@eit.lth.se

***Abstract*—For more than 30 years since it was first proposed by Harrington *et al*., the Theory of Characteristic Mode (TCM) has only been applied to perfect electric conductors (PEC), and more recently lossless dielectric materials. One key challenge in computing the characteristic modes (CMs) of non-PEC materials using the PMCHWT surface integral equation is the presence of internal resonances in the solution space, due to the required forcing of symmetry on the impedance matrix. In lossless dielectrics, it was shown that these non-real CMs can be removed in post-processing through far-field power analysis. However, this method breaks down in lossy materials as it relies on the assumption of no radiation losses. This paper proposes the use of basis function perturbation to isolate the non-real CMs from the real CMs when CM analysis is applied to lossy materials.**

Keywords*—*Characteristic modes, antenna design, dielectric resonator antennas.

I. Introduction

Recently the antenna community has become intrigued by the significant benefits obtained through the computational analysis of an object using the Theory of Characteristic Modes (TCM) [1]. This excitement stems from the characteristic modes (CMs) of the object providing important insights on its radiation properties without prior placement of excitation sources. In particular, these CMs contain the full set of orthogonal currents and near-fields which the object supports, facilitating applications including the excitation of specific antenna pattern shapes, the design of highly-decoupled multi-antennas for multiple-input multiple-output (MIMO) systems, and the placement of antenna feeds to excite large structures (e.g., aircraft and ship). However, due to problems associated with the method of moments (MoM) impedance matrix used in surface equivalent problems (SEP), applications of TCM have been limited to perfect electric conductors (PEC). Although the Poggio-Miller-Chan-Harrington-Wu-Tsai (PMCHWT) surface integral equation (SIE) formulation for MoM can be forced into symmetry to obtain CMs for dielectric and magnetic materials [2], the approach generates internal resonant modes. Recently, it was shown that these non-real CMs radiate a small amount of power and therefore can be removed through far-field power analysis in post-processing [3]. However, lossy materials present a significant problem as the radiation efficiencies of real CMs are not only less than unity, but can be significantly smaller. This means the non-real CMs cannot be effectively isolated based on radiated powers. Herein, it will be shown that when basis function perturbation is used, non-real CMs can be isolated from the solution space in post-processing, even for the case of lossy materials.

This work was supported by Swedish Research Council under Grants No. 2010-468 and No. 2014-5985.

II. Removal of Internal Resonant Modes

In [2], Harrington *et al.* propose a method of forcing the asymmetric PMCHWT SIE MoM impedance matrix into symmetry. The resulting symmetric impedance matrix allows the eigenmode decomposition presented in [1] to diagonalize the impedance matrix. This diagonalization results in an orthogonal set of characteristic currents, which when properly normalized, will ideally radiate unitary far-field power. However, the adaptation which forces the PMCHWT impedance matrix into symmetry causes non-real, internal resonant modes to form in the solution set. If ideal expansion functions that perfectly describe the object's electromagnetic properties are used, the non-real CMs will radiate zero far-field power, and thus cannot be normalized. However, in practice the MoM impedance matrix is formed using non-ideal expansion functions, such as those built from Rao-Wilton-Glisson (RWG) edge elements. RWG edge elements imperfectly describe the object and as such the basis functions cannot be perfectly characterized. As these basis functions are not perfect, the non-real CMs of the structure will radiate some power; therefore, the radiated far-field power can be properly normalized. Once normalized, the non-real CMs of a lossless object will radiate some amount of power less than unity. Nevertheless, as the object is lossless all real CMs should radiate with zero losses. The modes which radiate less than unity power can be extracted and attributed to internal resonances [3]. However, this concept is not valid for lossy materials, as they reduce the radiation efficiency of all real CMs. Additionally, the normalized currents of the non-real CMs can radiate much more than zero far-field power.

Power radiated from non-real CMs is described by the approximate expansion functions used to solve for the MoM impedance matrix. As such, in theory it is possible to remove the non-real CMs through a MoM mesh perturbation. The PMCHWT MoM impedance matrix is built on the basis of current flow across adjacent edge elements. If the mesh is varied, the currents must also vary, thus impacting the basis functions that form the impedance matrix. Changing the mesh (i.e., changing the individual basis functions) will change how the non-real CMs are normalized, as well as how they will radiate far-field power. This change will relate to a change in the type and amount of far-field power radiated by non-real CMs. If the same mode under two different mesh perturbations radiate different amounts of far-field power, or the radiated pattern changes significantly, the mode can be associated with an internal resonance (i.e., a non-real CM). The total radiated power for each mode can be found using (18) in [1], whereas the total amount of pattern variance can be found using (3) in [4]. To demonstrate this method, the CMs of a dielectric sphere will be evaluated under different loss conditions. It will be shown that some modes have a constant far-field efficiency and pattern upon mesh perturbation, whereas other modes do not.

III. Mesh Perturbation Example

To determine the effectiveness of mesh perturbation on identifying non-real CMs, a dielectric sphere was analyzed at 300 MHz for three different loss parameters, i.e., loss tangents (tan δ) of 0 (lossless), 0.01 and 0.1. The sphere is approximated by 1206 basis functions, and it has a radius of 0.2 meters and a dielectric constant ε_r of 10.0. Two different mesh perturbations with an average mesh variance of 32% (see Fig. 1), as calculated by determining the two closest vertices and averaging over the mean edge length, were used to calculate the total radiated power difference as well as the total change in the far-field pattern shape. If the power varied by more than 10% or the far-field envelope correlation coefficient (ECC) was less than 0.85, the mode is attributed to a non-real CM.

The lossless sphere (tan δ = 0) contains three modes which radiate with nearly unitary efficiency (i.e. Modes 9, 10, and 11). The lossy sphere (tan δ = 0.1) has eight modes which radiate with greater than 20% efficiency and all modes radiate with less than 75% efficiency. The efficiency of these modes for mesh 1 are: mode 1 = 23%, 2 = 26%, 4 = 31%, 6 = 37%, 9 = 72%, 10 = 73%, 11 = 72%, and 12 = 62%. When analyzing the total change in the far-field power between the meshes (see Fig. 2) and the ECC (see Fig. 3), the modes with sufficiently high power variance and low ECC can be attributed to internal resonances. Analysis of the sphere with tan δ = 0 confirms that modes 1-8, and 12 can be associated with internal resonances, leaving modes 9-11 associated with real CMs. The analysis of the sphere with tan δ = 0.01 shows that modes 1-6, 8, and 12 can be removed, thus allocating modes 7, and 9-11 to real CMs. Analysis of the sphere with tan δ = 0.1 results in the removal of modes 3-8, and 12, and the allocation of modes 1-2, and 9-11 to real CMs. To confirm if mode 7 (tan δ = 0.01), and modes 1-2 (tan δ = 0.1) are real CMs, two more mesh perturbations were evaluated. These additional calculations revealed that only modes 9-11 of all spheres are real CMs.

IV. Conclusions

The external fields of the non-real CMs computed using CM analysis of the symmetric PMCHWT MoM impedance matrix depend on the distribution of the basis functions used. Therefore, mesh perturbation can be utilized to vary the basis functions, and analysis can be performed in post-processing to determine the real CMs. If the external fields of the same mode vary under two different basis function perturbations, the mode can be attributed to a non-real CM. However as the demonstrated example reveals, it is not yet understood how much a mesh should be perturbed to guarantee sufficient variation in the external fields of all non-real modes and hence their identification. Therefore, multiple perturbations may be needed to guarantee the removal of all internal resonant modes of a lossy object.

References

[1] R. F. Harrington and J. R. Mautz, "Theory of characteristic modes for conducting bodies," *IEEE Trans. Antennas Propag.*, vol. 19, no. 5, pp. 622-628, Sep. 1971.

[2] Y. Chang and R. F. Harrington, "A surface formulation for characteristic modes of material bodies," *IEEE Trans. Antennas Propag.*, vol. 25, no. 6, pp. 789-795, Nov. 1977.

[3] H. Alroughani, *et al.*, "Observations on computational outcomes for the characteristic modes of dielectric objects," in *Proc. IEEE Int. Symp. Antennas Propag.*, Memphis, TN, USA, Jul. 6-11, 2014, pp. 844-845.

[4] Z. Miers and B. K. Lau, "Wide band characteristic mode tracking utilizing far-field patterns," *IEEE Antennas Propag. Lett.*, vol. 14, pp. 1658-1661, 2015.

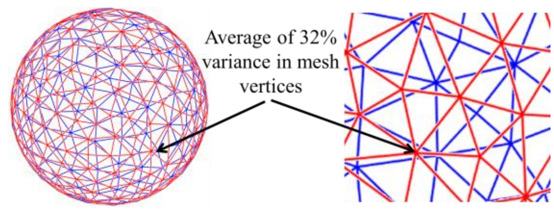

Fig. 1. Two different RWG mesh structures are shown in red (mesh 1) and blue (mesh 2), the average mesh variance between mesh 1 and mesh 2 is approximately 32%.

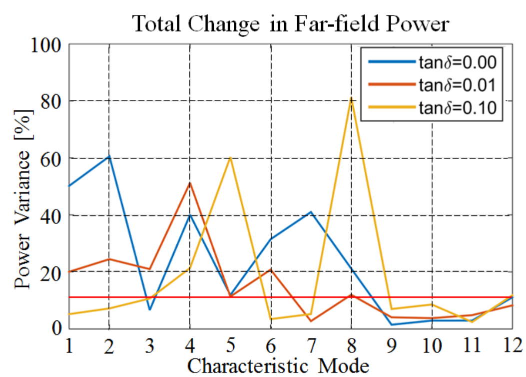

Fig. 2. Total change in far-field power for the first twelve CMs for each of the different loss cases. Modes 9, 10, 11 radiate unitary power when tan δ = 0.

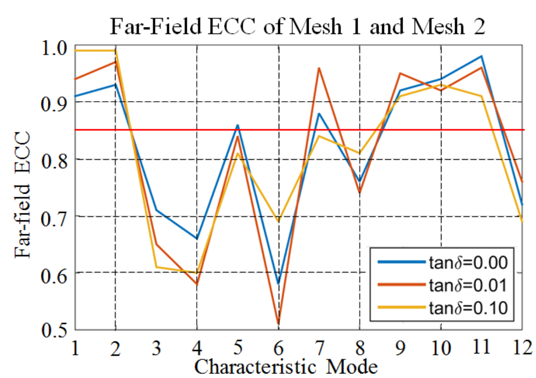

Fig. 3. Value of the far-field ECC of the first twelve CMs for each of the different loss cases. Modes 9, 10, 11 radiate unitary power when tan δ = 0.