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Tracking of Characteristic Modes Through Far-Field Pattern Correlation

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***Abstract*—Recent developments in characteristic mode (CM) analysis enable a more systematic approach to designing multi-antennas for mobile terminals. However, some of the advantages of developing antennas through CMs are based on accurate mode tracking over frequency. Existing tracking methods are primarily based on the tracking of eigencurrents over frequency, by which mode swapping and degenerate modes can occur. To solve these problems, a completely different method of tracking CM by means of far-field pattern correlation was recently developed and shown to work well for perfect electric conductors (PECs). This paper reveals that the same method can also substantially reduce tracking errors for structures with both PEC and dielectric materials, relative to state-of-the-art methods.**

I. Introduction

The Theory of Characteristic Modes (TCM) [1] was formulated in the 1970's as a valuable tool for synthesis and optimization of antennas; however, at the time multiple-input multiple-output (MIMO) antenna systems had not yet been developed and TCM received relatively little attention in the antenna community. In 2007, it was first noted that since characteristic modes (CMs) provide mutually orthogonal radiation patterns, the efficient excitation of different modes by the antenna ports facilitates low correlation and hence optimal MIMO performance [2]. Based on this initial idea, TCM has since been applied to optimize antenna placement in predefined structures [3], [4], synthesize antennas with reconfigurable patterns [5], and help create more than one excitable mode at frequency bands below 1 GHz while also achieving multiband capability [3]. Furthermore, recent progress has enabled substantially more efficient computation of CMs for lossless structures containing both perfect electric conductor (PEC) and dielectric materials [6]. This allows any predefined lossless structure to be optimized using CM-aided antenna design.

Even though significant progress has been made in these design methodologies, most of them require proper tracking of CMs over wide frequency bands. Until recently, mode tracking methods were based on correlating either the eigenvalues or the eigenvectors (eigencurrents) across frequency. The most popular one is the modal assurance criterion method (MACM), which computes a correlation matrix of the eigencurrents across two distinct frequency points and links eigencurrents with high enough correlation to the same mode [7]. However, a new method based on correlating characteristic far-field patterns [8] was shown to significantly reduce the number of degenerate and swapped modes for a PEC structure. This method sorts the eigenvalues in ascending order from the lowest eigenvalue to the highest eigenvalue. Once sorted, the standard envelope correlation coefficient (ECC) equation [1] is applied to two characteristic far-field patterns at adjacent frequencies rather than two different antennas at the same frequency. If two patterns are calculated to have a correlation higher than a predefined value, the corresponding eigenvalues are then linked to the same CM. This process is repeated until all CMs have been tracked. In this paper, this method was applied to a structure with both PEC and dielectric material. The computed eigencurrents for the structure were significantly more complex in behavior than those for PEC-only structures. As such, the standard current-based tracking methods require a fine frequency step size to accurately track each CM. However, using the method in [8], no mode swapping or degenerate modes were observed even for much larger step sizes.

II. Mode Tracking of Structure with Dielectric

Current-based tracking solutions such as MACM break down for complex structures and coarsely spaced frequency points. As an example, MACM was applied to a 130 mm × 66 mm PEC (with zero thickness) surrounded by 2 mm of lossless vacuum ("air dielectric"). The vacuum can be considered the simplest dielectric material, which ideally has no influence on the CMs of the PEC plate alone [3]. The first nine eigenvalues were computed using the surface integral equation (SIE) solution as described in [6]. It is noted that the SIE approach solves for the electric and magnetic fields based on equivalent currents on the surfaces of the structures. Therefore, two separate sets of currents were computed, the eigencurrents located on the surface of the vacuum, as well as those on the PEC conductor sandwiched within the vacuum. The solution was calculated at nine discrete frequency points between 500 MHz and 2 GHz. The defined structure utilized 4874 Rao-Wilton-Glisson (RWG) triangle elements.

The MACM-tracked CMs as shown in Fig. 1 do not match the CMs for the flat PEC plate [3]. The increased complexity of the structure due to the inclusion of the surrounding vacuum and the 187.5 MHz coarse frequency step size caused the mode-tracking algorithm to fail in regions of high eigenvalues. This failure is due to the continuous evolution of the eigencurrents on both the boundary surfaces of the vacuum as well as the PEC plate across frequency; as the frequency step size is increased, the correlation between the eigencurrents of the same mode at different frequencies decreases.

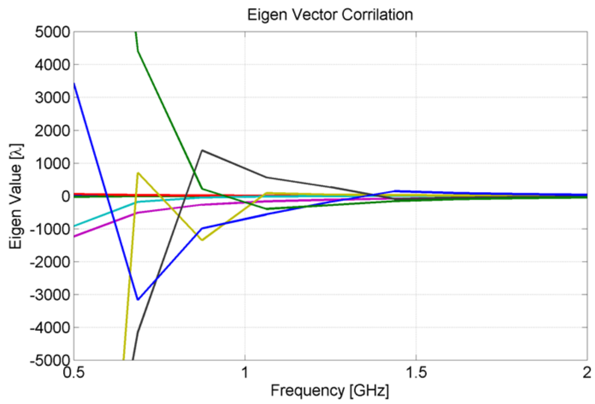

Fig. 1. Mode-tracking using MACM for a 130 mm × 66 mm PEC surrounded by 2 mm of vacuum.

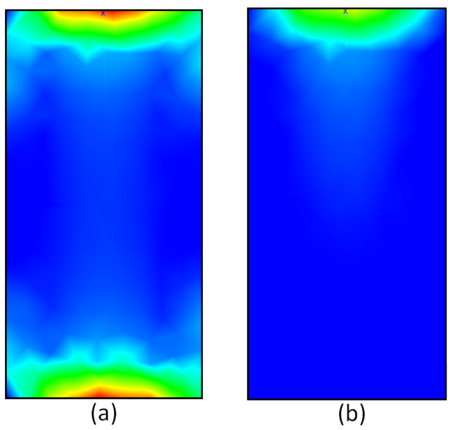

Fig. 2. Eigencurrents of the second eigenmode of a metal plate surrounded by vacuum at (a) 1 GHz and (b) 2 GHz.

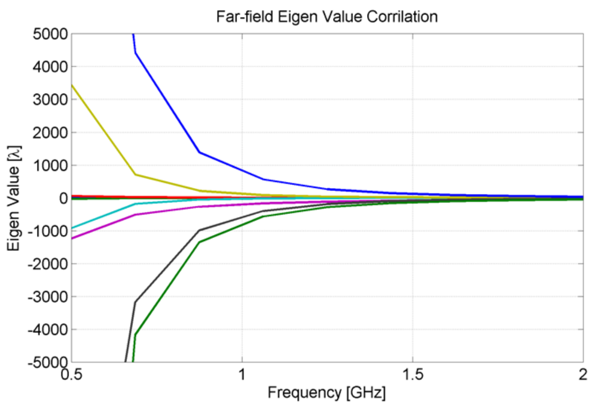

Fig. 3. Far-field mode-tracking of a 130 mm × 66 mm PEC surrounded by 2 mm of vacuum.

In contrast, the far-field correlation method of [8] correctly tracks the nine CMs of the same structure, as shown in Fig. 3. The success of the method is due to the low complexity and slow evolution of the characteristic far-field patterns over frequency. The results in this paper are based on an elevation (theta) step size of 10° and an azimuth (phi) step size of 10°, containing a total of 703 discrete sample points. The tracked eigenmodes remained the same as the far-field step size was increased to 20° in both theta and phi, reducing the number of sample points to 190. The far-field correlation was found to be lowest in mode six, yielding an ECC of 0.95 at a frequency step size of 187.5 MHz and an ECC of 0.59 between 500 MHz and 2 GHz (step size of 1.5 GHz). No mode swapping was observed even with an extremely coarse step size of 1.5 GHz. Using this coarse step size, the ECC for the second most correlated mode against mode six was found to be below 0.3, further establishing the robustness of this far-field approach.

III. Conclusion

In this work, it was demonstrated that the far-field correlation based mode tracking method presented in [8] provides accurate mode tracking not only when applied to structures containing only PEC but also to structures which contain both PEC and dielectric material.

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