Predicting Electromagnetic Interference to a Terminated Wire Using Characteristic Mode Analysis

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***Abstract*—Electromagnetic coupling to realistic wire configurations exhibit large variations with respect to the frequency, incident angle, and polarization of the interfering signal. In this work, Characteristic Mode Analysis (CMA) is used to calculate the fundamental modes of a terminated wire above an infinite ground plane. Using the properties of the modes, the coupled currents to the wire's loads are predicted for different incident excitations. Using this simple but practical wire configuration, we show the versatility of CMA in practical electromagnetic interference and coupling applications.**

***Keywords*—Characteristic mode analysis, field-to-wire coupling, interference.**

I. Introduction

In a highly congested wireless spectrum, electromagnetic interference poses a significant challenge in a wide range of applications. Therefore, predicting the coupling or interfering current to a particular load in a practical wiring system has received rising interest over the last decade [1], [2]. For a particular wire configuration, several simulations and/or measurements are needed to exhaustively quantify the variations in the coupled currents due to variations in the frequency, angle of incidence, and polarization of the interfering signal. In this work, Characteristic Mode Analysis (CMA) is applied to predict the coupling to a terminated wire above an infinite ground plane. CMA decomposes the currents induced on a scatterer in terms of a set of independent modes and quantifies the modal behavior such as the relative importance of each mode at the frequency of interest [3]. In this work, we show how this modal behavior can be used to guide coupling and interference to practical wire systems.

II. Computational Analysis

A. Wire Configuration

Fig. 1 shows a 1 m wire, 3 mm in radius, and at a height of 0.1 m above an infinite ground plane. The wire is terminated at both of its ends by 50 Ω loads labelled as Load 1 and Load 2, respectively. Moreover, a third 50 Ω load, Load 3, is attached to the middle of the wire. In spite of the simplicity of the configuration in Fig. 1, it has practical relevance in a wide range of studies [4]–[6]. In the next Sub-section, we show how CMA can be used to simplify the coupling analysis to the different loads in Fig. 1.

B. Characteristic Mode Analysis of the structure

The CMA of the wire configuration in Fig. 1 is performed using the commercial electromagnetic solver FEKO [7]. The components of the CMA are threefold: (*i*) the modal significance spectrum (Fig. 2), (*ii*) the modal current distribution(Fig. 3), and (*iii*) the modal fields or the radiation characteristics of each mode (Fig. 4) [8]. In the context of electromagnetic interference, the modes represent all possible pathways for the external electromagnetic radiation to couple to the wire configuration in Fig. 1. The modal current distribution and the modal significance are completely independent of the external excitation. The modal fields represent the coupling between the incident field and the modes. That is, the modal field patterns can be defined as the map of the electric field directions that minimize/maximize the coupling between the incident radiation and a particular mode.

III. Electromagnetic Interference Results

CMA provides the current distribution of the fundamental modes of the structure allowing the prediction of the response at different wire locations. For example, Fig. 3 shows that only the even modes, Modes 2, 4 and 6, have nonzero currents at the middle of the wire. Thus the middle load, Load 3, is immune to coupling from the odd modes. Starting with Mode 2, Fig. 4 shows that Mode 2 is more efficiently excited by an excitation at incidence angles of $\theta = 90^\circ$ and $\Phi = 45^\circ$ (the green curve). Fig. 3 shows that Mode 2 resonates at 0.3 GHz. Therefore, Mode 3 should be strongly expressed in the coupled current to Load 3 at 0.3 GHz for an incident plane wave at angles of incidence $\theta = 90^\circ$ and $\Phi = 45^\circ$. On the other hand, Fig. 2 shows that Mode 6 resonates at 0.9 GHz and Fig. 4 shows that Mode 6 can be most efficiently excited at angles of incidence $\theta = 50^\circ$ and $\Phi = 0^\circ$. Therefore, at angles of incidence $\theta = 50^\circ$ and $\Phi = 0^\circ$ maximum coupling should occur at 0.9 GHz which is the resonance frequency of Mode 6.

To test this hypothesis, Fig. 5 shows the coupled current to Load 3 for two different excitations. Clearly, the current coupled to Load 3 is maximum at 0.3 GHz when $\theta = 90^\circ$ and $\Phi = 45^\circ$, due to the strong excitation of Mode 2, and the current coupled to Load 3 is maximum at 0.9 GHz when $\theta = 50^\circ$ and $\Phi = 0^\circ$, due to the excitation of Mode 6.

For the terminal loads, Load 1 and Load 2, all the modes have high current values at the load locations as shown in Fig. 3. However, for frequencies below the resonance frequency of the first mode, i.e., frequencies below 0.15 GHz, only Mode 1 will contribute to the current coupled to the terminal loads because it will be the only mode that is significant as shown in Fig. 2. Fig. 4 shows that if the incident field is exerted at $\theta = 90^o$ and $\Phi = 90^o$, maximum coupling to Mode 1 will occur which will directly maximize the coupling to the terminal loads. For these angles of incidence, the maximum coupling to the terminal loads will occur at the resonance frequency of Mode 1, 0.15 GHz, as shown in Fig. 6. As the frequency

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increases, the higher-order modes, both odd and even, will start contributing to the current coupled to the terminal loads according to their modal significance shown in Fig. 2 and their modal fields in Fig. 4. The example studied in this paper shows the versatility of CMA in quantifying and predicting coupling. A similar CMA approach can be used to quantify and predict coupling to wire systems that are more complex than the one shown in Fig. 1 which will be presented at the conference.

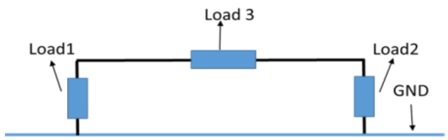

Fig. 1. Terminated wire above perfectly conducting ground plane.

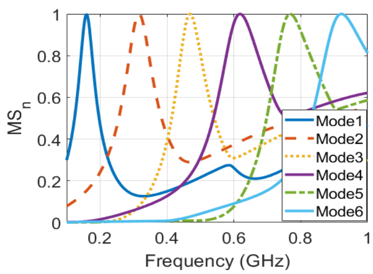

Fig. 2. Modal Significance of the wire configuration shown in Fig. 1.

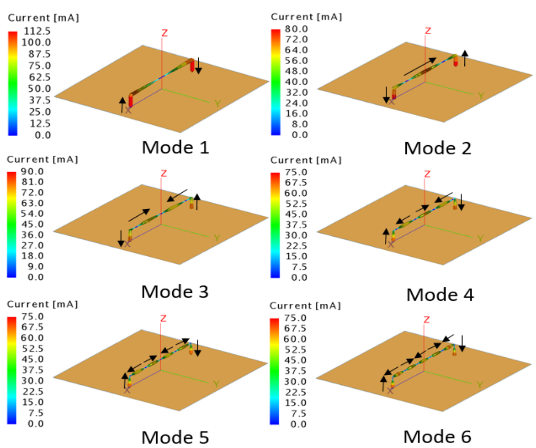

Fig. 3. Modal currents of the first 6 modes of the wire configuration.

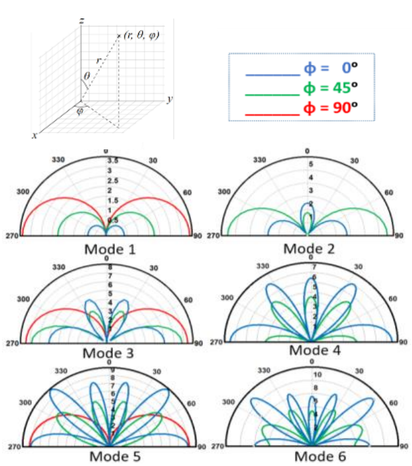

Fig. 4. Modal fields of the first 6 modes of the wire configuration shown in Fig. 1.

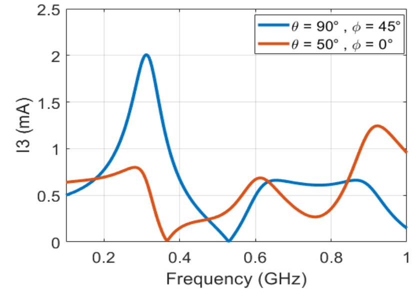

Fig. 5. Induced current on Load 3 for different field orientations.

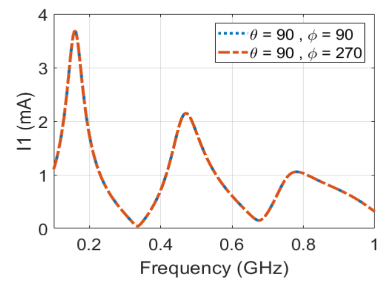

Fig. 6. Maximum induced current on Load 1.

IV. Conclusion

A simple wire configuration with three loads was studied to predict and control the coupling to each load individually at different frequencies. Characteristic Mode Analysis (CMA) was applied to identify all the modes of the structure and the possible ways to maximize/minimize coupling to each mode. This study will be extended in the future to study more complex wire systems and experimental validations of the CMA predictions will be presented.

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