Characteristic Modes for the design of compact radiators on complex platforms

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Abstract

The placement of a communication system on a three-dimensional platform always poses a series of problems that the antenna designer has to solve or mitigate for guarantee the desired functional operability. Among the several challenges, the need of compact and conformal radiators is one of the hardest tasks to accomplish, especially if working on objects whose dimensions are comparable to the wavelength of interest. The solution to this problem can be pursued by using the Characteristic Mode Analysis.

1. Introduction

Small-size antennas are appealing solutions for managing communications on complex platforms where space is a scarce resource. However, due to intrinsic physical limits, the dimension of a resonant radiating element is directly proportional to the operative wavelength. This fact can have dramatic consequences for the designer if the addressed wavelength is comparable to the platform dimension. The interaction between the designed antenna and the platform need to be carefully evaluated as well. Moreover, if frequency or radiation pattern reconfigurability is a requested antenna feature [1],[2], then the goal is even tougher to tackle.

Characteristic Mode Analysis (CMA) can provide useful guidelines for the design of non-resonant elements that are able to exploit the hosting platform as the main radiating object. In CMA the current flowing on a conductive body surface is expressed in terms of a linear superposition of orthogonal current modes [3]. The selective excitation of these current modes can be advantageously exploited for several different tasks spanning from the design of small/conformal antennas, MIMO antennas as well as pattern and polarization reconfigurability. In addition to the small space required by this approach with respect to solutions resorting to resonant elements, the CMA allows to intrinsically consider the effect of the platform on the radiation properties of the antenna structure.

2. Characteristic Mode Theory

CMA determines the current modes that a conducting body is able to support. These modes are obtained by solving the generalized eigenvalue equation that is derived from the Method of Moments (MoM). The identified modes are found without considering any kind of excitation since they only depend on the shape and the size of the investigated structure. These modes are a convenient base where to expand the total surface current (J_{tot}) that can be found on a conducting body. More in detail, J_{tot} can be written as a linear superposition of current modes:

$$J_{tot} = \sum_n \alpha_n J_n \tag{1}$$

where α_n represents the modal weighting coefficients of the characteristic mode and J_n represent the current distribution of the n^{th} mode. Furthermore, α_n can be calculated as:

$$\alpha_n = \frac{V_n^i}{1 + j\lambda_n} \tag{2}$$

where λ_n are the eigenvalues associated to the modes. The other two factors that contribute to the modal weighted coefficient of the modes are the modal significance (MS) of a mode, which is equal to:

$$MS = \left| \frac{1}{1 + j\lambda_n} \right| \tag{3}$$

and the modal excitation coefficient equal to:

$$V_n^i = \left\langle J_n, E^i \right\rangle = \oiint_S J_n \cdot E^i dS \tag{4}$$

where S is the surface of the conductive body and E^i the external excitation. Although the MS is independent of any kind of excitation, the terms V_n^i takes into account the effect of the external excitation applied, including the position, magnitude and phase. Consequently, the inner product $<J_n,E^i>$, represents the coupling between the exciter and the n^{th} current mode, which quantifies the capacity of the applied source to excite a particular mode.

3. Discussion

A rough model of a vehicle is reported in Fig. 1a. (W = 2.1 m, L = 3.5 m, H = 1 m). The CMA is performed within a frequency range between 50 MHz and 80 MHz. It is interesting to observe that the relative wavelengths are comparable to the vehicle dimensions and therefore a resonant antenna would require a significant space for its placement. The eigenvalues (λ_n) of the first eight characteristic modes as a function of the frequency are reported in Fig. 2. The eigenvalues are real numbers and a mode is considered at resonance when its associated value is equal to zero. The area highlighted in green corresponds to a MS greater than 0.8. By observing the results, it is apparent that in the frequency range of interest the most significant modes are Mode#1, Mode#3 and Mode#4 since they are the closest to zero over the whole bandwidth. The current distribution associated to each mode is illustrated at the center frequency of 65 MHz in Fig.1(b)-(e). The radiation pattern produced by a mode is, by definition, orthogonal to all the other ones and this property allows combining them in order to control the radiation pattern [4], [5]. However, each mode has to be properly excited and the kind, place and number of exciters requires careful study, especially on three-dimensional platforms [6],[7].

4. Conclusions

Example of CMA exploitation for designing the proper exciter on complex platforms will be provided as well as suitable design guidelines.

Acknowledgements

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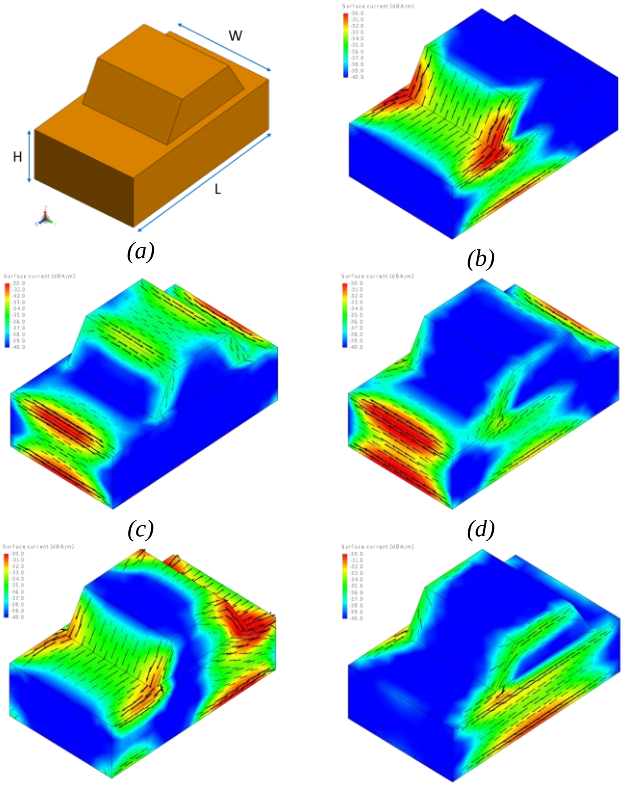

(a) *(b)* *(c)* *(d)* *(e)* *(f)*

Figure 1: Rough model of the considered vehicle (a) and current distributions at 65 MHz of Mode#1 (a), Mode#2 (b), Mode#3 (c), Mode#4 (d), Mode#5 (e) and Mode#6 (f).

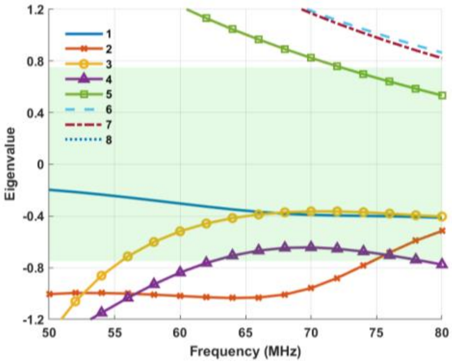

Figure 2: Plot of the first eight eigenvalues within the considered frequency bandwidth (50MHz-80 MHz).

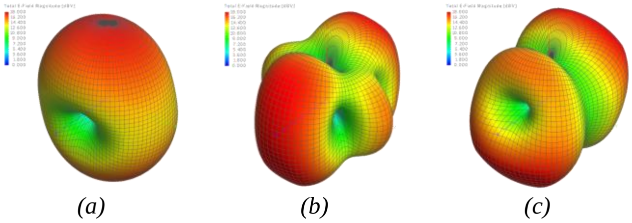
(a) *(b)* *(c)*

Figure 3: Radiation pattern associated with Mode#1 (a), Mode#3 (b) and Mode#4 (c).

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