Design of multi-antenna feeding for MIMO terminals based on characteristic modes

Miers, Zachary; Li, Hui; Lau, Buon Kiong

Published in:
IEEE International Symposium on Antennas and Propagation, 2013

DOI:
10.1109/APS.2013.6710752

2013

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

Design of Multi-Antenna Feeding for MIMO Terminals Based on Characteristic Modes

Zachary Miers, Hui Li, and Buon Kiong Lau
Department of Electrical and Information Technology
Lund University
223 63 Lund, Sweden
Buon_Kiong.Lau@eit.lth.se

***Abstract*—Conventional antennas in single-antenna terminals that resonate at frequencies lower than 1 GHz usually rely on the chassis as the main radiator. To effectively exploit chassis excitation for MIMO terminals, each of the multiple antennas is required to excite one distinct chassis mode. However, in today's terminals, there is typically only one chassis mode that can radiate efficiently at frequencies below 1 GHz. Fortunately, it has been shown that minor modifications in the chassis structure can cause more than one mode to resonate at these frequencies. Nevertheless, proper antenna feeding methods are needed to practically tap into these modes. In this paper, we propose a general technique to feed orthogonal chassis modes of a given conducting structure using the theory of characteristic modes. By separating a radiating structure into individual modal currents, the near field radiating properties are exploited for capacitive or inductive feeding without significant coupling to other orthogonal modes of radiation. As a proof of concept, we apply the technique to feed a modified terminal chassis that has two significant characteristic modes at 0.89 GHz.**

I. INTRODUCTION

The recent introduction of multiple-input multiple-output (MIMO) technology complicates terminal antenna design, since MIMO requires more than one antenna element to be active simultaneously at a given frequency band [1]. Moreover, these antennas must be electromagnetically isolated from one another in some ways to ensure high efficiency and low signal correlation, which result in good MIMO performance [1].

For frequencies lower than 1 GHz, it is well established that the terminal chassis, rather than the antenna element, often acts as the main radiator [2]. Moreover, since typical terminal chassis sizes only provide one chassis radiation mode or characteristic mode (CM), implementing multiple antennas can lead to simultaneous excitation of the only CM, resulting in severe coupling among the antennas [3].

To overcome the severe chassis-assisted coupling, a new design concept is proposed in [4] to obtain more than one resonant CM for frequencies below 1 GHz. In particular, a small modification of the chassis structure, such as the addition of a metallic bezel originally intended for aesthetic reasons, can yield this desirable result [4]. However, it is not immediately obvious in [4] how one can practically feed these modes with either self-resonant antennas [2], [3] or non-resonant coupling elements [5], [6]. Moreover, the feeding structures are often not included in the CM analysis and their introduction in the final design can exert non-negligible impact on the CMs [6]. This is especially true for multiple self-resonant antenna elements, since they are typically larger than coupling elements and can together form a significant part of the chassis structure. Therefore, it is important to ensure an appropriate feeding type and its location for a given CM, as well as the impact of the feed on other CMs to maintain high orthogonality among the multiple antenna elements.

In [6], CM analysis was used to realize and feed multiple orthogonal modes. The optimal feed locations are determined by the locations of the minimum and maximum characteristic currents for each driven mode. In this paper, we present a new and innovative approach of analyzing and designing effective feeding for the CMs of a general conducting structure. As opposed to using the characteristic currents [6], the proposed approach is based on the reactive near-field behaviors of the CMs. The CM near-fields provide insights into where coupled energy can be maximized for a given mode, while reducing the probability of coupling to other modes. As an illustrative example, the feed design technique is applied to a terminal chassis at a frequency where two resonant CMs exist [6], so that two antennas offering good MIMO performance of high efficiency and low correlation are obtained.

II. DESIGN OF ANTENNA FEEDING

In [4], the chassis of a candy-bar style mobile terminal with dimensions of 120 mm × 60 mm was designed using CM analysis to provide two resonant CMs at frequencies below 1 GHz. To achieve the two resonant CMs, the structure is loaded with a metallic bezel, which is shorted to the chassis at the midpoint of one of the short chassis edges.

Based on this structure, the characteristic currents and reactive near-fields are analyzed in order to design appropriate feeds for the two CMs. To allow some space for antenna feeding and retain the original dimensions, we first shortened the longer side of the original structure in [4] by 10 mm, giving a new chassis area of 110 mm × 60 mm (see Fig. 1). As given in [4], the vertical gap between the bezel and the chassis is 2 mm and the thickness of the bezel is 3 mm. The characteristic currents of the two CMs are shown in Fig. 1, and they can give insight into possible current feeding locations to excite each mode [6]. However, to mitigate possible coupling between the current feeds due to each feed introducing non-negligible current into more than one CM, we propose to consider feed design based on the reactive near-fields of the modes, which are shown in Fig. 2. To excite Mode 2, it is a common to use a folded monopole at one end of the chassis [3], where the electric field is strong, as observed in Fig. 2(c). To design the feed for Mode 1, we first studied the magnetic near fields in the z direction (H_z), where the two modes are significantly different. It is observed that the H_z component of Mode 2 is strong around the center of the chassis length, whereas that of Mode 1 is strong at the corners. Consequently, to reduce coupling between the modes, Mode 1 can be excited with an inductive coupling element above the corner of the chassis.

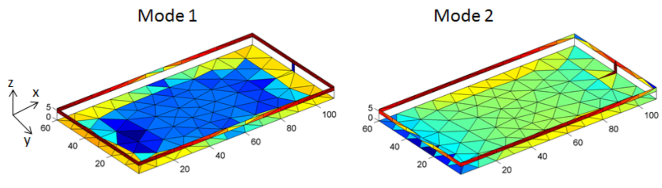

Figure 1: Characteristic currents of Modes 1 an 2 at 0.89 GHz.

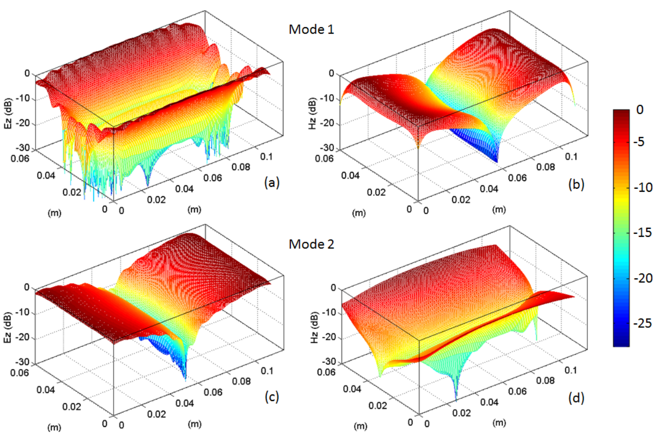

Figure 2: Normalized magnitudes of electric and magnetic fields of both modes at 0.89 GHz.

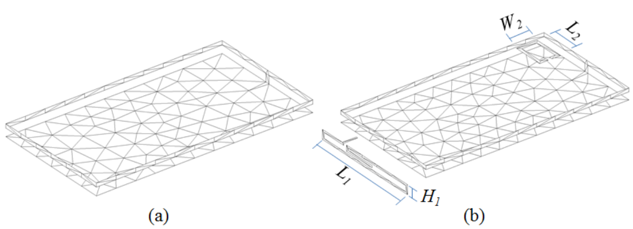

Fig. 3. (a) Initial bezel-loaded chassis, (b) Final design with feed elements embedded into chassis (L_1 = 60 mm H_1 = 5 mm, L_2 = 16.4 mm W_2 = 11.4 mm).

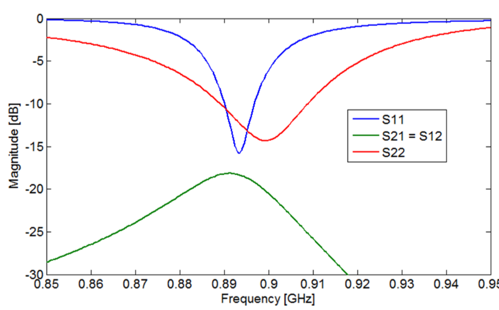

Fig. 4. Scattering parameters of the two-port antennas.

The geometries of the resulting two-port antenna structure are shown in Fig. 3(b). A loop (Port 1) and a folded monopole (Port 2) are used to excite Modes 1 and 2, respectively. The scattering parameters of the two-port design were obtained using full-wave antenna simulation in the frequency domain of CST Microwave Studio (see Fig. 4). To match the antenna feed of each mode to a 50 ohm source, a single lumped element was used at each port. It is observed in Fig. 4 that the resonances occur around 0.89 GHz and the isolation is above 17 dB. Orthogonal radiation patterns, which are not presented due to space limitation, are obtained by the two antennas.

Once the feed structures were embedded into the design, the CMs were re-calculated. The eigenvalues of the chassis with feed structures show only slight differences from those of the initial bezel-loaded structure, as shown in Fig. 5.

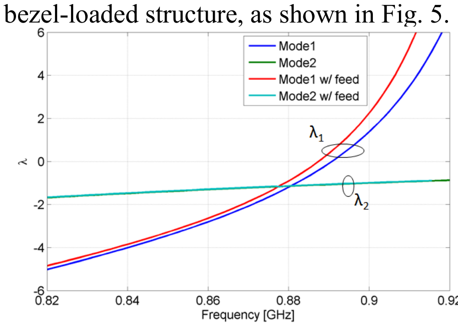

Fig. 5. Eigenvalues of both modes with and without the feeding structures.

III. Conclusion

In this paper, we investigated the new concept of using CM near-fields to selectively excite the CMs of a conducting structure. For the example of a terminal chassis, two resonant modes were excited at 0.89 GHz by first contrasting individual CM near fields with each other. Using this information, an appropriate feed type and location was designed to excite each mode. The two antennas in the final design achieve an isolation of 17 dB, indicating successful excitation of the individual modes. Future research will be directed into extending the bandwidth and lowering the frequency of the two modes, as well as further simplifying the feed structures for these modes.

Acknowledgments

This work was supported in part by VINNOVA under grant no. 2009-04047, and in part by Vetenskapsrådet under grant nos. 2010-468 and 2012-4859.

References

[1] B. K. Lau, C. Oestges, A. Sibille, and A. Zanella, Eds., "Multiple antenna terminals," in MIMO: From Theory to Implementation. San Diego, CA: Academic Press, 2011, pp. 267–298.

[2] P. Vainikainen, J. Ollikainen, O. Kivekas, and I. Kelander, "Resonator-based analysis of the combination of mobile handset antenna and chassis," *IEEE Trans. Antennas Propag*., vol. 50, no. 10, pp. 1433–1444, Oct. 2002.

[3] H. Li, B. K. Lau, Z. Ying, and S. He, "Characteristic mode based tradeoff analysis of antenna-chassis interactions for multiple antenna terminals," *IEEE Trans. Antennas Propag.*,vol. 60, no. 2, pp. 490–502, Feb. 2012.

[4] H. Li, Z. Miers, and B. K. Lau, "Generating multiple characteristic modes below 1 GHz in small terminals for MIMO antenna design," *IEEE Int. Symp. Antenna Propag. (APSURSI '2013),* submitted.

[5] J. Villanen, J. Ollikainen, O. Kivekas, and P. Vainikainen, "Coupling element based mobile terminal antenna structure," *IEEE Trans. Antennas Propag*., vol. 54, no. 7, pp. 2142–2153, July 2006.

[6] R. Martens, E. Safin, and D. Manteuffel, "Inductive and capacitive excitation of the characteristic modes of small terminals," in *Proc. Loughborough Antennas Propag. Conf. (LAPC'2011)*, Loughborough, UK, Nov. 14-15, 2011