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Design of Multimode Multiband Antennas for MIMO Terminals using Characteristic Mode Analysis

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***Abstract*—Characteristic mode analysis provides unparalleled insights into designing high performance multiple-input multiple-output (MIMO) terminal antennas at frequencies where the antenna elements are constrained to be electrically small. Conventionally, an electrically small single-antenna utilizes the fundamental characteristic mode of the terminal chassis to obtain sufficient bandwidth while maintaining high radiation efficiency. However, modern MIMO terminals require two or more antennas per frequency band, and they tend to excite the same fundamental chassis mode, resulting in severe coupling, correlation, and poor overall system performance. Recently, characteristic mode analysis of the chassis is proposed to design highly efficient multimode multiband MIMO antennas with significant bandwidth using electrically small feed elements. Two distinct and excitable characteristic modes were created at frequencies above and below 1 GHz, for a typical smartphone's form factor. This paper provides an overview of the method and highlights its versatility for practical implementation in standard plastic cased smartphones as well as in the popular metal-bezeled smartphones, with only minor modifications to the chassis.**

I. INTRODUCTION

To realize high data rates with multiple-input multiple-output (MIMO) technology, Long Term Evolution (LTE) mandates the implementation of two or more antennas in mobile terminals per operating frequency band. Moreover, optimal MIMO performance requires the multi-antennas to be highly efficient and uncorrelated with one another.

The Theory of Characteristic Modes (TCM) [1] presents unique insights into designing highly efficient and uncorrelated antennas on a single terminal chassis. Each individual characteristic mode as extracted from this theory can be defined as an independent uncorrelated antenna radiation mode. If any given mode has a low enough characteristic eigenvalue, a feed can be designed to excite that particular antenna mode on the given structure [2]. Often an electrically compact structure (e.g., a smartphone at LTE700) will not support the feeding of multiple modes with a low enough characteristic eigenvalue over a significant bandwidth. Utilizing the technique described in [2] and [3], it is possible to decrease the characteristic eigenvalue of a mode on a given structure so that multiple modes with significant bandwidth are excitable at frequencies where the terminal chassis remains electrically compact. This is accomplished through minor, and industry-acceptable, chassis modifications [3]. Furthermore, to support multiband resonances, the modified structure's characteristic near-fields and currents around the antenna feeds can then be correlated with higher frequency characteristic modes. Correlated higher frequency modes can then be shifted through a further slight modification of the chassis and excited using the low frequency feeds [2].

In this paper, we summarize the multiband, uncorrelated antenna design method as applied to two significantly different terminal chassis, i.e., a standard plastic encapsulated single PCB chassis [2] as well as the recently popular metal-bezel equipped chassis [1]. Both chassis were designed to support multiple antennas with multiband performance. These antennas were designed, simulated, and measured to have total antenna efficiencies of above -2dB and envelope correlation coefficients (ECC) of below 0.1 in all bands [2], [1].

II. MULTI-ANTENNA DESIGN

In [2], the chassis of a modern smartphone with the dimensions of 130 mm × 66 mm was designed using TCM to provide two resonant characteristic modes (CM) at frequencies above and below 1 GHz. The standard unmodified flat chassis only supports one resonant characteristic mode below 1 GHz, as can be seen in Fig. 1. In an effort to attain more than one resonant mode below 1 GHz, the structure must be modified. There are many ways to change a flat chassis which will result in different CMs. However, by analyzing the original characteristic currents, and near-fields, antenna matching techniques can be used to modify the chassis and help increase the resonance of non-resonant modes. The chassis only supports two modes with a characteristic eigenvalue (λ) between ±15 below 1 GHz. λ_1 is the fundamental mode with dipole-like currents along the length of the chassis, λ_2 supports currents resembling those of a short, fat dipole along the width of the chassis. Based on standard antenna design techniques, it is reasonable to load the longer ends of the chassis with strips of metal to increase the capacitance of the λ_2 current distribution and thus bring this mode into resonance. The metal strips reduced the characteristic eigenvalue of the non-resonant dipole-like currents running along the width of the chassis. This minor modification changed the CMs of the structure to support the two resonant modes λ_1 and λ_2. The modified λ_1 and λ_2 were fed using a standard capacitive coupling element along the top end of the chassis and a direct current feed attached to one of the two capacitive loading strips, respectively (see Fig. 2(a)).

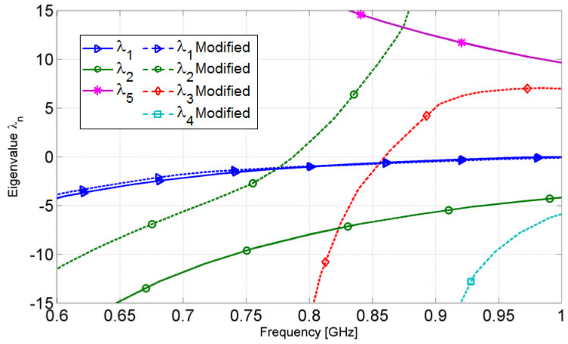
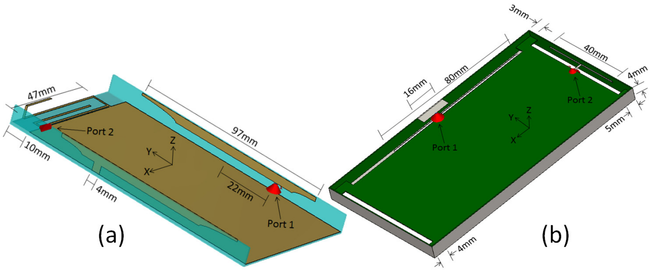


Fig. 1. Characteristic eigenvalues of a 130 mm × 66 mm chassis with and without shorted metal strips along the longer ends.

To create multiband operation using the low frequency excitation points, the currents around the low frequency feeds were correlated with the CMs at higher frequencies. The currents around Port 2 were highly correlated to a CM which was resonant near 1.6 GHz. By reducing the length of one section of the capacitive loading strips, the correlated CM shifted from 1.6 GHz to the desired second resonance at 1.85 GHz. This modification did not impact the low frequency mode of operation. Through the addition of the shortened capacitive loading strips, the new structure supports two uncorrelated excitable antennas covering LTE Bands 5, 6, and 19 below 1 GHz as well as LTE Band 2 above 1 GHz with an ECC of less than 0.1 and total efficiencies of greater than -2dB. The final design of this antenna is shown in Fig. 2(a).



(a)

(b)

Fig. 2. Multimode multiband terminal antennas designed using CM analysis: (a) plastic encapsulated chassis and (b) bezel chassis.

In [1], a bezeled mobile terminal chassis of the same dimensions and using the same design procedure as in [2] was developed. However, the design procedure did not appear to reduce the characteristic eigenvalue of any mode, but rather revealed it was possible to shift the frequency response of two different modes that were resonant at different frequencies. This created two excitable chassis modes that were resonant near the same frequency, i.e., λ_2 Modified and λ_3 Modified, as seen in Fig. 3. This was done by adjusting the gap and offset of the PCB from the bezel thus disrupting the characteristic currents around the bezel that were produce by a λ_3 feed in the unmodified chassis. λ_2 Modified produced a modal current distribution resembling that of a resonant loop antenna and λ_3 Modified produced a current distribution resembling that of a flat dipole antenna. As the gap is varied, λ_2 becomes resonant at higher frequencies whereas λ_3 becomes resonant at lower frequencies. λ_2 Modified was feed with a direct current feed between the bezel and the main PCB while λ_3 Modified was fed using a capacitive feed between the bezel and the PCB.

When correlating the low frequency feeds with the currents and near-fields at higher frequencies, it was found that the two feeds were highly correlated and could not independently excite the structure without significant correlation while maintaining the feed placement required for the low frequency excitations. In order to enable dual-band operation in this structure, an additional characteristic mode was created through further chassis modification. It should be possible to independently feed this new characteristic mode by only one of the two low frequency feeds. This was achieved through the addition of a slot in the ground plane that could be excited through near-field coupling from the current feed of λ_2 Modified. With slight modifications to the width and the height offset of this feed, substantial near field coupling around the feed can be produced in the direction of the ground plane at 1.85 GHz. This coupling is capable of exciting a slot type antenna. The addition of a slot allowed for two independent modes to be fed, covering LTE Bands 5, 6, and 19 as well as LTE Band 2. The final structure can be seen in Fig. 2(b).

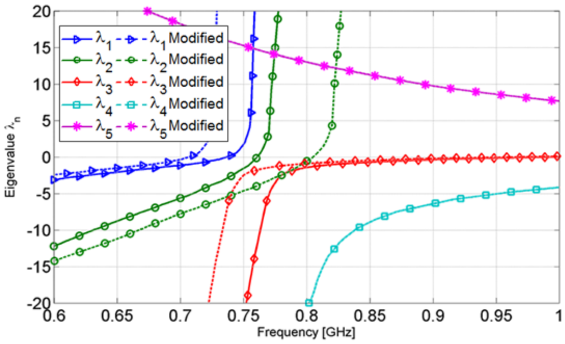


Fig. 3. Characteristic eigenvalues of a bezel chassis with and without chassis modifications.

III. CONCLUSION

This paper highlights the effectiveness and practicality of the characteristic mode design procedure presented in [2] for achieving multimode multiband MIMO antennas in an electrically compact chassis. Two significantly different chassis were investigated for MIMO antenna implementation using this procedure: a single flat PCB in [2] and [3] and a bezeled chassis in [1]. Both designs produced multiple multiband uncorrelated antennas with sufficient bandwidth and high efficiencies for LTE operation. The applicability of the procedure for other chassis structures and under other practical implementation constraints is the subject for future work.

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