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Generating Multiple Characteristic Modes below 1GHz in Small Terminals for MIMO Antenna Design

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Abstract—**Designing multiple antennas in small terminals at frequency bands below 1 GHz is challenging due to severe mutual coupling among antenna elements. The severe coupling is often the result of simultaneous excitation of the fundamental characteristic mode of the terminal chassis by more than one antenna element. In this work, we propose to solve the coupling problem by manipulating the chassis structure to allow more than one characteristic mode to resonate at frequencies below 1 GHz. To demonstrate our design concept and its practicality, we show the opportunistic use of the metallic bezel popular in smartphone design for obtaining two characteristic modes that can be efficiently excited by antenna elements at 0.81 GHz. Due to the inherent orthogonality of the modes, proper excitation of these modes by two antenna elements will result in orthogonal radiation patterns and high isolation between the antenna ports. Therefore, the proposed approach enables the effective use of the chassis to achieve MIMO antennas with good performance.**

I. INTRODUCTION

Due to the widespread adoption of multiple-input multiple-output (MIMO) technology in existing and upcoming wireless communication standards, successful design and integration of multiple antennas in user terminals is becoming increasingly important to terminal device vendors [1]. However, limited by the relatively small size of today’s terminals, the multiple antennas are closely spaced, leading to severe mutual coupling and MIMO performance degradation [1]. Accordingly, many effective decoupling techniques have been reported in the literature, including the use of multiport matching network, ground plane modification, neutralization line, and parasitic scatterer (see [1] and references therein). More recently, it has been shown that three characteristic modes of a 120 mm × 60mm chassis can be excited at 2.5 GHz by proper feeding to provide good isolation and orthogonal radiation patterns across three antenna ports [2]. Nonetheless, the aforesaid decoupling techniques are mostly demonstrated for terminal applications at frequency bands above 1.8 GHz.

At frequencies below 1 GHz, the decoupling of multiple antennas is far more challenging, due to the tendency of multiple antennas to simultaneously excite the same (i.e., fundamental) chassis mode, which induces severe coupling. To mitigate chassis-induced coupling, existing strategies rely on having only one antenna that excites the chassis, whereas the other antenna(s) minimizes chassis excitation by either: (1) optimizing the antenna location [3] and type [4] based on the electric and magnetic field distributions of the fundamental mode, or (2) localizing the current in the vicinity of the antenna element [5]. In this way, good isolation is achieved, without sacrificing the large impedance bandwidth obtained by the first antenna through exciting the fundamental mode.

In this work, we propose a new design approach that manipulates the chassis structure so that more than one characteristic mode is effectively excited at frequencies below 1 GHz. To illustrate the design concept, we use the example where a metallic bezel is used on the terminal casing, which is popular in smartphone design. By appropriately shorting the bezel to the chassis, we show that apart from the fundamental mode, a second characteristic mode can be made to resonate at 0.81 GHz.. In a companion paper [6], we describe the design of antenna feedings to effectively excite these two modes.

II. CHARACTERISTIC MODE ANALYSIS

Based on the Theory of Characteristic Mode (TCM) [7], the characteristic eigenvalues of a terminal chassis with the size of 120 mm × 60 mm were calculated (see Fig. 1). It is observed that only one mode (λ_1) resonates at around 1 GHz, which is the fundamental chassis mode (flat dipole mode) [3]. To obtain more characteristic modes that resonate at around 1 GHz, the chassis structure should be modified in a reasonable manner.

One possible modification is to load the chassis with a shorted bezel along its periphery, as shown in Fig. 2. The bezel is connected to the center of one short edge of the chassis. The eigenvalues of the bezel-loaded chassis are presented in Fig. 3. Besides the fundamental chassis mode, which is λ_2 in the figure, a new bezel mode (λ_1) is generated, whose eigenvalue is close to zero at frequencies around 0.81 GHz. Thus, two orthogonal modes can be excited at frequencies around 0.81 GHz. From the slope of the eigenvalues curves, the bandwidth of the bezel mode is expected to be narrow, whereas the bandwidth of the fundamental chassis mode is wide.

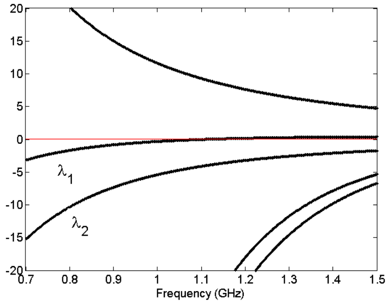


Fig. 1. Characteristic eigenvalues over frequency for a 120 mm × 60 mm chassis.

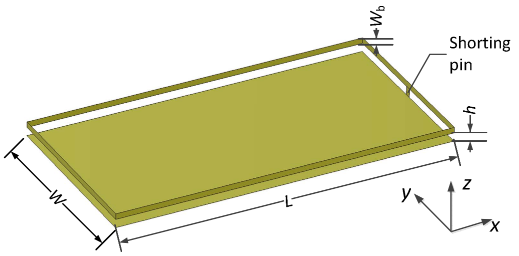


Fig. 2. Geometries of the chassis loaded with a shorted bezel. The dimensions are: L = 120 mm, W = 60 mm, W_b = 2 mm, h = 3 mm.

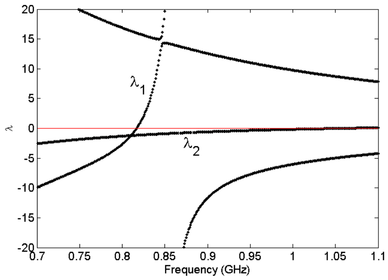
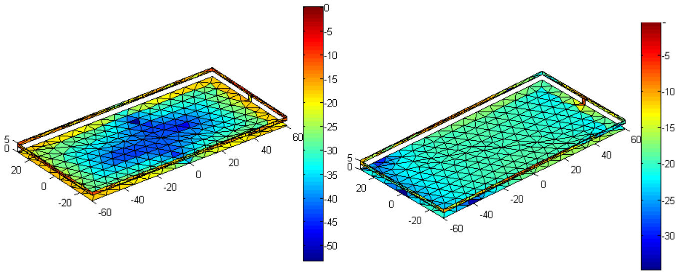
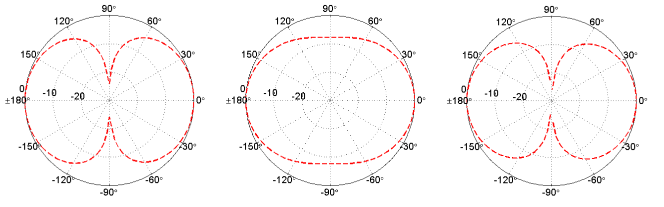


Fig. 3. Characteristic eigenvalues over frequency for the bezel-loaded chassis.

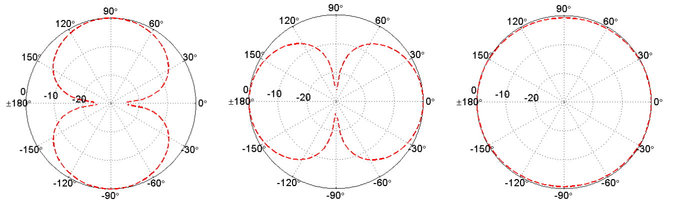


(a) Bezel mode (b) Fundamental chassis mode

Fig. 4. Normalized characteristic currents of the modes at 0.81 GHz.



(a) BM, *xy* plane (b) BM, *xz* plane (c) BM, *yz* plane



(d) FCM, *xy* plane (d) FCM, *xz* plane (f) FCM, *yz* plane

Fig. 5. Characteristic patterns of the bezel mode (BM) and fundamental chassis mode (FCM) at 0.81 GHz.

The number of shorting pins can be utilized to change the resonant frequency of the bezel mode: more shorting pins lead to higher resonant frequency. However, the shorting pins need to be symmetrically placed along the chassis sides, so to not disturb the fundamental chassis mode. For example, if only one shorting pin is used at a corner of the chassis, the slope of the eigenvalue curve for the fundamental chassis mode will greatly increase, resulting in narrower bandwidth. The bezel height and width can also affect the resonant frequency of the bezel mode.

The current distributions of the two orthogonal modes are shown in Fig. 4. The bezel mode shows a one-wavelength variation along the periphery of the bezel. For the fundamental chassis mode, the current is strong along the two longer edges of the chassis and the bezel.

The characteristic far-field patterns of the two modes are presented in Fig. 5. On the *xy* plane, the magnitudes of the patterns are perfectly complementary with each other. On the *xz* and *yz* planes, there are some overlaps around $\theta = 0°$ and $\theta = 180°$. However, the polarizations of the two antennas are different and remain uncorrelated. By analyzing the near-fields of the two modes, effective antenna feeds can be applied to excite orthogonal modes, delivering good MIMO antenna performance at frequencies below 1 GHz [6].

III. CONCLUSIONS

In this work, we have shown that a new resonant mode, which is orthogonal to the fundamental chassis mode, can be generated at frequencies below 1 GHz by adding a bezel to the chassis structure. The parameters of the bezel-loaded chassis are analyzed with respect to their impacts on the two modes. The current distributions and characteristic patterns of these two modes highlight the orthogonality between them. Hence, generating orthogonal modes at frequency bands below 1 GHz to achieve good MIMO antennas is a promising new design concept. Possible future work includes bandwidth enhancement of the modes and effective mode excitation methods.

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