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Effects of Internal Components on Designing MIMO Terminal Antennas Using Characteristic Modes

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Abstract— **The Theory of Characteristic Modes has been shown capable of facilitating the development of many high-quality antennas through providing the characteristic modes (CMs) inherent to a structure. The CMs will change if the structure is altered; this property has been used to adapt terminal antennas, enabling good MIMO performance in compact structures. Previously these designs focused on altering the terminal structure without consideration into the effects of essential internal components on the desired CMs. Components such as touch screens, cameras, microphones, and batteries will change the CMs of the structure, which can in turn lead to the CM-based MIMO antennas to become non-orthogonal or non-resonant. Until now, relatively little work has been done to analyze the impact of these internal components on CM-based antennas. This article studies the effects internal components on the CMs of a MIMO terminal chassis, and how these effects can be mitigated.**

Index Terms—**MIMO systems, characteristic modes, terminal antennas**

I. INTRODUCTION

Traditionally, antenna engineers design antennas primarily through alteration of known antenna designs, optimization of the currents and near-fields of previously designed antennas, or computer-executed design optimization. While these methods can work extremely well, they often rely on the intuition of an experienced antenna engineer to understand the true dynamics, and physics, behind how antennas are created to meet specific requirements for a given application. As such, few physical insights are available to enable a systematic design framework. Interestingly, it was shown over 40 years ago that the currents, near-fields, and far-fields a structure is able to support can be found prior to implementing antenna structures and feeds through the Theory of Characteristic Modes (TCM) [1]. This concept allows an antenna design to start from a known structure, rather than a predefined antenna, and utilizes physics based insights obtained from the characteristic modes (CMs) to design an antenna. By knowing how a given structure radiates, TCM can be used to optimize and tune a structure to radiate in a way that meets a set of specific performance goals [2], [3].

Utilizing the physical insights obtained from the CMs of a structure, it has been shown how these modes can be used to design and analyze a variety of different antenna problems including radar scattering analysis [4], excitation of large structures with coupling elements (CE) [5], wide-band antenna analysis [6], pattern reconfigurable antenna design [7], and chassis based multiple-input multiple-output (MIMO) antenna

design [2]. However, the focus of existing TCM literature is on designing antennas using the CMs of a structure's frame or chassis rather than using those of the complete structure. The CMs of a structure depend on the structure's shape and size, and they will change if the structure is altered. In terminal application, the addition of components such as batteries, displays, cameras, and speakers can have a significant impact on the CMs a terminal chassis can support.

In this work, we analyze the impact internal components have on the CMs of a MIMO terminal antenna which has been designed using TCM [2]. It will be shown that internal components can have a significant impact on the resonant frequencies and excitability of CMs. Consequently, these components should be included in the base design.

II. MODAL VARAIATION OF INTERNAL COMPONENTS

CM analysis is a frequency domain modal analysis technique used to solve for the orthogonal currents and fields that an object is capable of generating. An initial mobile phone chassis with dimensions 130 mm × 66 mm was analyzed using CMs in [2]. The CMs inherent to this chassis structure do not support multiple orthogonal antennas below 1 GHz. In an effort to adapt the chassis to support multiple antennas, the flat chassis (PCB) was modified using standard antenna theory and the known CMs of the structure. New modes were formed in the chassis through the addition of capacitive loading structures attached to both sides of the chassis (similar as in Fig. 1 but without the components, henceforth called modified chassis (MC)). The antenna feed positons of the MC were then found through analysis of the characteristic currents and near-fields. However, the analysis in [2] did not consider the structures' CMs when internal components are placed within the chassis. Hence, this paper extends the work in [2] by analyzing the MC with internal components (MCIC), as shown in Fig. 1. As can be seen in the figure, the internal metallic components of a typical cellphone occupy a significant volume within the chassis. These components are all modeled by perfect electric conductors and consist of the following: electromagnetic compatibility (EMC) LCD screen backing plate, battery enclosure, speaker, and microphone.

The addition of each internal component changes the CMs of the structure in a manner which cannot always be predicted. The CMs of the initial chassis and the MC from [2] can be seen in Fig. 2. In the MC structure the currents associated with λ_1 resemble those of a resonant dipole with currents running

along the width of the chassis, λ_2 displays currents resembling a slot antenna between the chassis and the capacitive loading structure, λ_3 is the fundamental mode which resembles a dipole antenna along the length of the chassis. A component study was carried out which examined the changes which occurred in the CMs as a response to adding each component to the MC structure. The microphone, speaker, and screen increased the resonant frequency of λ_1 and did not have a significant impact on λ_2. The battery decreased the resonant frequency of λ_1 while increasing the quality factor (Q) of λ_2. When all the components were placed on the chassis, the resonant frequency and Q of λ_1 were significantly impacted whereas only the Q of λ_2 was impacted as can be observed in Fig. 2. The resulting shift in frequency and increase in Q no longer allow for the original required bandwidth to be effectively excited. Furthermore, if the modal far-field patterns and near-fields of the MC and the MCIC are correlated against each other the far-field patterns change by more than 10% and the location of the maximum electric near-field, which is used to properly excite the CMs, moves by more than 8 mm along the length of the chassis. These effects result in an antenna which no longer meets the original system requirements.

III. Tuning CMs to Meet Performance Goals

To support the required frequency and bandwidth in the MCIC, standard CM analysis can be applied and physical manipulation of the structure can be used to change the CMs. This can be done through analyzing the characteristic near-fields and currents associated with the MCIC structure. The change in characteristic attributes between the MC and the MC with a screen and battery can be used to show that the amount of coupled fields (capacitance) between the two capacitive loading plates increased with the additions of the screen and battery. These coupled fields can be reduced by reducing the size (or length) of the plates. However, from previous CM analysis it is known that the λ_2 resonance is dependent on the slot between the chassis and the loading plates. Therefore, if the plate length is reduced, the λ_2 resonance will increase in frequency. To avoid changing the λ_2 resonance while increasing resonant frequency of λ_1 the capacitive loading plates' width rather than the length should be reduced. Furthermore, by changing the slope of the gap between the plate and the chassis the Q of λ_2 can be reduced without significantly impacting its resonant frequency. These modifications allow for the CM resonances to be tuned and new excitation points chosen.

IV. Simulation Verification

The modified MCIC structure with similar antenna feeds as in [2] (with dielectric substrate and supporting structures) was simulated using the FEM solver in CST. The modal resonances of λ_1 and λ_2 were combined to extend the bandwidth of antenna 2, whereas the fundamental mode (λ_3) was used for antenna 1. The final design produced a 6 dB impedance bandwidth and better than 14.5 dB isolation from 824 MHz to 941 MHz (see Fig. 3). The far-field envelope correlation coefficient (ECC)

between port 1 (λ_3) and port 2 (λ_1 and λ_2) was below 0.1, and a total efficiency of better than -1.9 dB was achieved for both ports. An L matching network was used to match λ_1 and λ_2 (port 2), and a capacitive element was used to match λ_3 (port 1). Figure 3 also shows that the original antenna feeds designed using TCM for the MC (MCIC Org.) [2] could no longer be well matched to meet bandwidth requirements once internal components were integrated into the prototype.
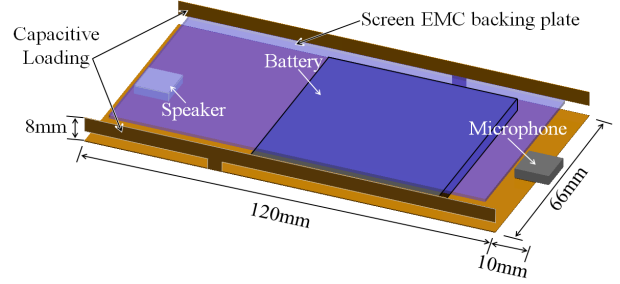

Fig. 1: Modified mobile phone chassis (called MC) designed using TCM with the addition of standard internal components. The modified chassis with internal components as shown in the figure is denoted as MCIC.
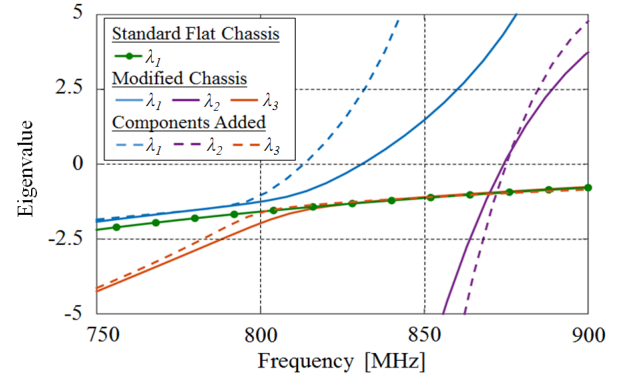

Fig. 2: Sub-1GHz band resonant CMs of the initial chassis (standard flat chassis), the MC from [2], and the MCIC (components added).
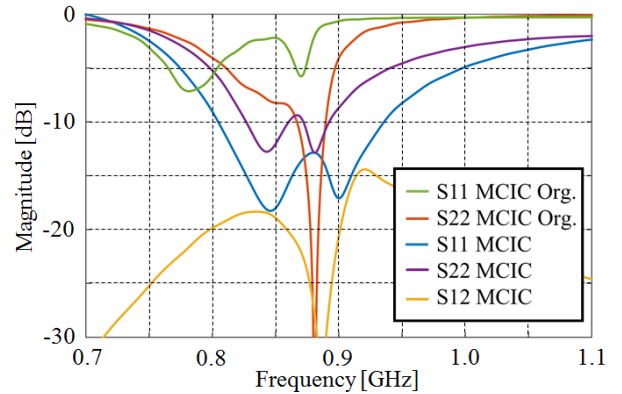

Fig. 3: Simulated reflection coefficients of the original antenna prototype from [2] when loaded with internal components (MCIC Org.) and the scattering parameters of the modified prototype designed together with internal components using TCM (MCIC).

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