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On Modal Excitation Using Capacitive Coupling Elements and Matching Network

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***Abstract*— A resonant characteristic mode (CM) is useful for antenna design if it is properly excited and well matched to the source. In this paper, we consider the feed design for the excitation of the fundamental CM of a rectangular chassis. The tradeoff between the required number of capacitive coupling elements (CCE) and matching elements used for achieving a given antenna bandwidth is studied. The results reveal that in order to attain the modal bandwidth of the fundamental mode, the use of multiple CCEs with optimal placement and phase simplifies the required matching network.**

Keywords*—*Capacitive coupling element; characteristic modes; chassis excitation; impedance bandwidth; matching network

I. Introduction

The fundamental characteristic mode (CM) of a rectangular conductive plate, which models a smartphone's chassis, is known to be very wideband, going from below 1GHz and extending beyond 5GHz for typical form factors. However, existing attempts to excite this mode using non-resonant coupling elements (CEs) are mostly confined to more modest single- or dual-band coverage, i.e., whole or part of the LTE low band (698-960MHz) and mid band (1.71-2.17GHz) [1], [2]. The reason behind the large performance gap in potential vs. achieved bandwidth has not been studied. Moreover, the ability of antennas to offer larger bandwidths is practically important due to more bands being used by 4G and 5G systems. Previously, multiple CEs were mostly used for increasing the number of ports in MIMO applications in the low band [3], or providing selective excitation of CMs in the mid band [4]. In this paper, CM analysis (CMA) is used to explain the modest bandwidth of previous designs. Further, multiple CEs are utilized to excite the chassis' fundamental mode. It is shown that the required complexity of the matching network can be reduced by placing more correctly dimensioned and phased CEs in the right locations.

II. Chassis Excitation: Simulation Results

In this work Altair FEKO 2018 was used for CMA and BetaMatch software for matching network (MN) design. The MN is limited to a maximum of five cascaded lumped elements. The simulations are performed with a lossless matching circuitry, phase shifters (PSs) and power dividers (PDs). Moreover, non-resonant capacitive CEs (CCEs) are used in this study, as they provide more compact antenna solutions important for practical application.

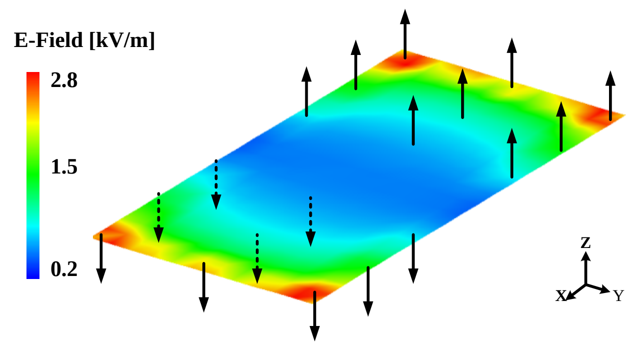

Fig. 1. Magnetiude and phase of the electric field 3 mm above a 52 × 120 mm^2 plate. The direction of the arrow (of fixed length) shows the phase.

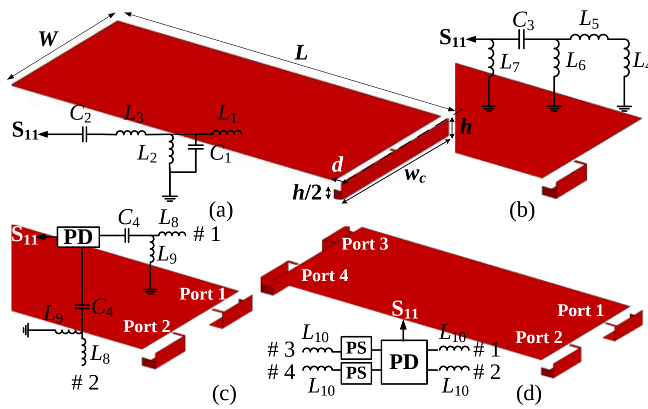

Fig. 2. (a) Wide off-ground center-feed CCE at one side of the chassis, W = 52 mm, L = 120 mm, d = 5 mm (0.02λ), w_c = 52 mm (0.09λ), h = 5 mm (0.02λ). λ is the freespace wavelength of the center frequency, (b) one small off-ground CCE at the corner, (c) two small CCEs at one side, (d) four CCEs at two sides. The optimized matching elements are: L_1 = 3.6 nH, L_2 = 3.5 nH, L_3 = 8.8 nH, C_1 = 5.8 pF, C_2 = 1.8 pF, L_4 = 27 nH, L_5 = 8.2 nH, L_6 = 24 nH, L_7 = 18 nH, C_3 = 1.5 pF, L_8 = 7.5 nH, L_9 = 13.1 nH, C_4 = 3.4 pF, L_{10} = 16.5 nH.

A. *Excitation of the fundamental mode by a single CE*

Based on the CMA of a 52 × 120 mm^2 perfect electric conductor (PEC) plate, the maximum electric near-fields of the fundamental mode are mainly at the four corners, with a 180° phase shift between the two smaller sides (see Fig. 1). To effectively excite this mode by a single CCE, the electric field strength around the CCE should be as high as possible, i.e., the volume of the CCE should be used efficiently. Thus, a self-resonant PIFA is not optimal since the voltage and also the electric field strength near the shorting pin of the PIFA are low. Fig. 2(a) shows a wide traditional off-ground center-feed non-resonant CCE which fully covers the width of the

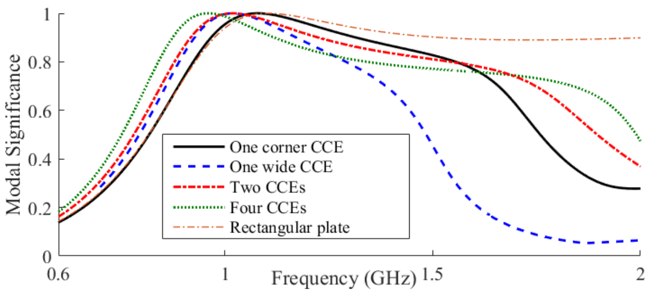

Fig. 3. MS of the fundamental mode for the rectangular plate without and with CCE(s).

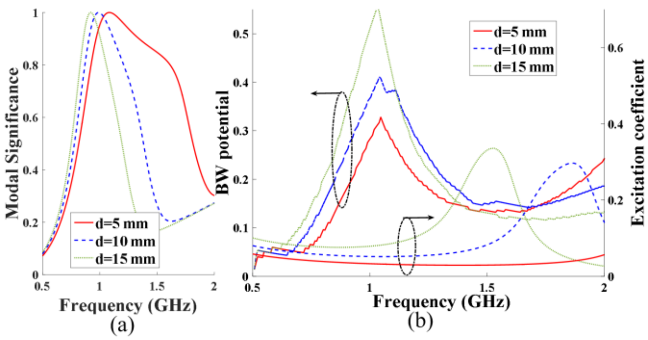

Fig. 4. (a) MS of the chassis combined with a single CCE at one corner for different *d*'s, (b) bandwidth potential and exitation coefficient for the CCE for different *d*'s.

plate [2]. The modal significances (MSs) of the fundamental mode of the rectangular plate without and with CCE(s) are plotted in Fig. 3. Considering the MS criterion of 0.5 for defining the modal bandwidth, it can be seen that there is no limit in modal bandwidth for the plate in the observed frequency range. However, mounting the aforementioned wide CCE (shorted for CMA) reduces this bandwidth. In Fig. 2(b), the volume of the CCE is reduced compared to the wide CCE in Fig. 2(a) and it is placed at one corner, around a region maximum field strength. As shown in Fig. 3, this step improves the modal bandwidth (0.8-1.6 GHz) relative to the wide CCE case, but it is still lower than that of the plate with no CCE. Figure 4(a) reveals that, by increasing the single corner CCE's off-ground clearance (*d*), the modal bandwidth of the fundamental mode decreases with respect to that of the rectangular plate. On the other hand, the bandwidth potential in Fig. 4(b) increases, since the CCE becomes more resonant at a lower frequency. Furthermore, the modal excitation coefficient also increases, although it will start to decrease as *d* is increased beyond a certain value [5].

Figure 5 shows the results of using a minimum number of matching elements to match the different CCEs in Fig. 2 (for $S_{11} < -6$dB) in the targeted MS bandwidth (0.8-1.6GHz). Five lumped elements are required for matching the wide CCE (see Fig. 2(a)). However, five matching elements is not enough to obtain this bandwidth for the small corner CCE.

B. Excitation of the dipole mode by multiple CCE

To benefit from the large modal bandwidth that the smaller corner CCE provides, the number of CCEs was increased. When two CCEs were placed in two corners on one side as shown in Fig. 2(c), the modal bandwidth is slightly larger than that of one corner CCE (see Fig. 3). Moreover, it can be matched to the targeted bandwidth using three elements for each CCE, as shown in Fig. 5. Thus, it can be seen that in order to increase the impedance bandwidth, instead of increasing the size of a single CCE which reduces the modal bandwidth, it is better to increase the number of elements placed at the right locations. By doing this one can also use a simpler matching network for each element. Taking this further, when four CCEs with antiphase feed between the two shorter sides were simulated (see Fig. 2(d)), the modal bandwidth is slightly better than that of Fig. 2(c) and the required matching to cover the targeted bandwidth is even simpler (i.e., one inductor for each CCE). Finally, if no phase shift is applied, the S_{11} result is poor, as shown in Fig. 5, since the CCEs were not properly coupled to the electric near-fields of the fundamental mode.

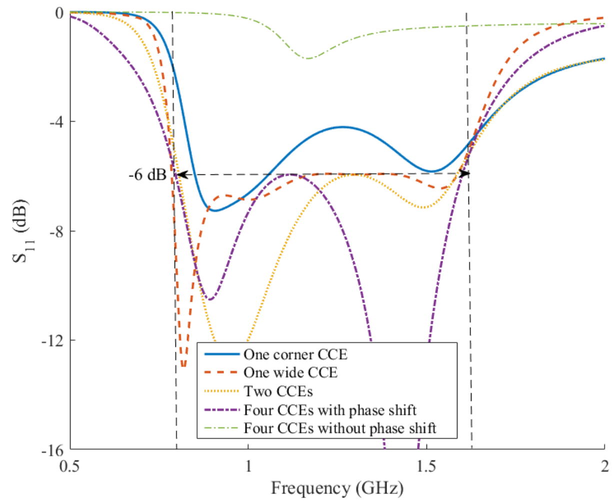

Fig. 5. S_{11} corresponding each configuration in Fig. 2.

III. Conclusion

This work shows that a capacitive coupling element can limit the modal bandwidth of the fundamental mode of a rectangular plate. However, multiple CCEs can be utilized to increase the modal bandwidth and obtain a given impedance bandwidth with simpler matching.

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