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Wideband Excitation and Matching of Fundamental Chassis Mode Using Inductive Coupling Element

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***Abstract*—It is known that the fundamental radiation mode of a mobile terminal chassis enables wideband coverage below 1 GHz. However, in theory, the bandwidth of this chassis mode extends infinitely beyond 1 GHz. In this paper, we investigate the use of inductive coupling element (ICE) to significantly increase the antenna bandwidth obtainable from the fundamental mode. Using characteristic mode analysis, a dual-ICE configuration is proposed and optimized to excite the fundamental mode, giving a simulated impedance bandwidth of nearly 100%.**

Keywords—Terminal antenna; characteristic modes; inductive coupling element; matching network; feed design

I. INTRODUCTION

Mobile terminal antennas were first designed for frequency bands below 1 GHz, and only a small bandwidth was required. However, as mobile communications became popular, many more frequency bands were added to meet growing demand. In particular, it is challenging to obtain more bandwidth for the bands below 1 GHz, due to space limitation constraining the antenna elements to be electrically small. Nonetheless, antenna designers have achieved bandwidths far beyond those expected of electrically small antennas. This phenomenon was found to be due to the terminal chassis, which is electrically much larger, becoming the main radiator [1]. The antenna element has instead taken the role of coupling power into the chassis, effectively exciting the fundamental mode of the chassis [2].

Today's terminal antennas offer multi-band coverage, with the low-band covering most of the range 0.7–1 GHz and the higher bands extending from around 1.7 GHz. Although these antennas meet current requirements, the low-band design does not exploit the full potential of the fundamental mode, which in theory has a bandwidth that extends to infinity (see Fig. 1).

In this paper, the design of low-band terminal antenna is revisited from the perspective of characteristic mode analysis (CMA) and impedance matching. It is shown that inductive coupling elements (ICEs) [3] can be applied to attain a much larger bandwidth than 0.7–1 GHz. To this end, key parameters for the excitation and impedance matching of the fundamental chassis mode were identified and optimized. Using the optimized structure and a suitable feeding network, the 6 dB impedance bandwidth of 98% (0.78-2.3 GHz) is achieved.

II. CHASSIS EXCITATION: SIMULATION RESULTS

Altair FEKO 2018 was used for CMA and BetaMatch Version 3.7.6 for bandwidth potential [1] estimation. In Fig. 1, the characteristic eigenvalues for an infinitely thin, 120 mm × 60 mm perfectly conducting chassis are shown. It can be seen that eigenvalue of the fundamental dipole mode (mode 1) is close to zero (resonant) from ~0.9 GHz onwards. Capacitive coupling element (CCE) can be used to excite this mode, but it was found in [4] that the use of CCE can severely limit the mode's bandwidth potential. Apart from CCE, ICE can also be used for modal excitation [3], through coupling power into the characteristic current. Figure 2(a) shows that the current of mode 1 is strongest along the two longer sides of the chassis, indicating that ICEs should be placed in these locations. Figure 1 shows that a simple ICE (a slot with a feeding strip) does not change the chassis' resonant modes in the observed frequency range. This means that the fundamental mode retains its infinite bandwidth, despite having the ICE.

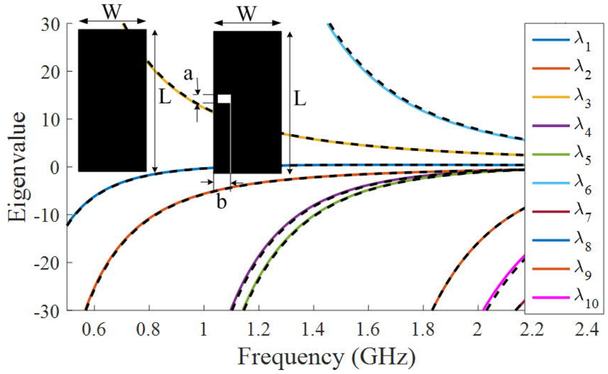
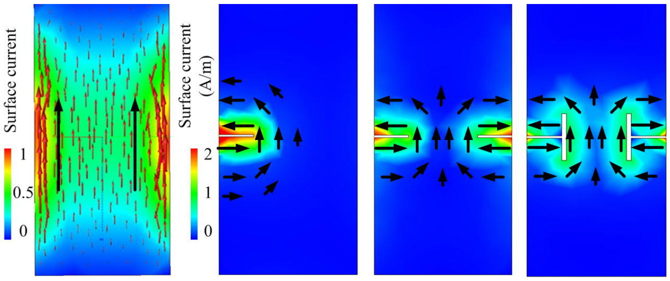


Fig. 1. Characteristic eigenvalues of solid chassis (solid lines) and slotted chassis (dashed lines). $W = 60$, $L = 120$, $a = 1$, $b = 3$ (units: mm). (The feeding strip at the outer end of the slot is shorted in characteristic mode analysis.)



(a) (b) (c) (d)

Fig. 2. (a) Normalized current of the fundamental mode at 0.9 GHz, and total currents in the rectangular plate with feeding at (b) one horizontal slot, (c) two horizontal slots, (d) two horizontal /vertical slots.

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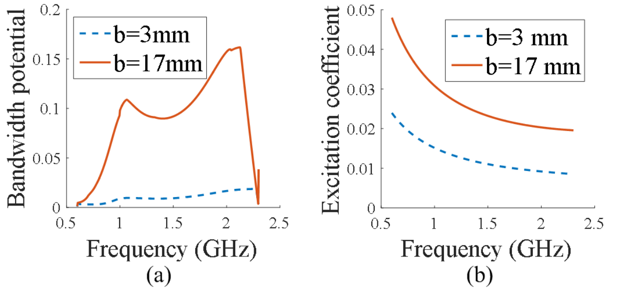

Fig. 3. (a) Bandwidth potential and (b) modal excitation coefficient of a rectangular chassis fed by an ICE with different slot length *b*.

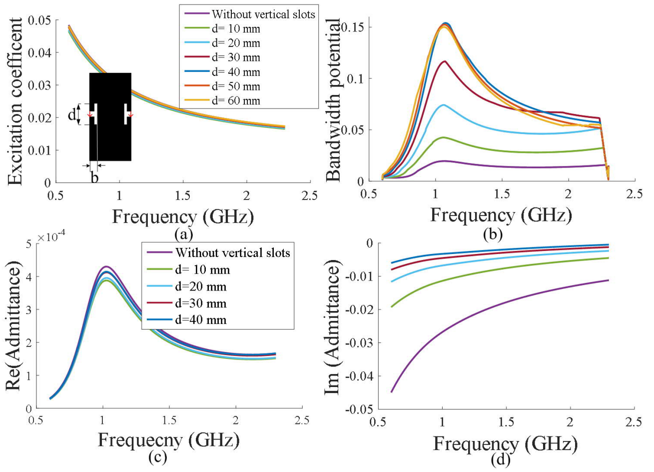

Fig. 4. (a) Modal excitation coefficent, (b) bandwidth potential, (c) real part of admittance and (d) imaginary part of admittance, for dual-ICE (b = 3 mm).

However, due to impedance mismatch, the bandwidth potential for the ICE is lower than 3% at 0.8 GHz, with 50Ω source impedance (see Fig. 3(a)). To further increase the excitation of mode 1, the slot length *b* can be increased (see Fig. 3(b)). This in turn improves the bandwidth potential because the radiation resistance will be increased, especially at the lower frequencies. Figure 2(b) shows the current on the chassis when the feeding strip of the ICE is excited.

However, the single-ICE design is unsuitable for wideband realization, as it also excites other modes that become resonant near 2 GHz in a manner that limits its bandwidth potential. Therefore, a dual-ICE design, with another ICE added to the other location of high current and excited in phase, is adopted. Figure 2(c) shows the current distribution when the dual-ICE is excited. This new design effectively limits the excitation of higher order modes and increases the modal excitation coefficient of mode 1. Despite the better performance of the dual-ICE, the bandwidth potential is still limited to 15% or less (Fig. 3(a)), due to the impedance mismatch at the feeding port. Borrowing the idea of matching stubs, vertical slots of length *d* can be added to the ICEs. As can be seen in Fig. 4, the vertical slots primarily improve the impedance matching, retaining almost the same level of excitation. As shown in Figs. 4(c) and 4(d), the vertical slots improve the bandwidth potential mainly by changing the imaginary part of the admittance, while the real part remains almost the same. However, the rate of increase of the bandwidth potential decreases as *d* increases (see Fig. 4(b)), as the feed is becoming resonant in the frequency range of interest. Based on these insights, the key parameters of *b* and *d* were optimized for both excitation and impedance matching.

III. FINAL STRUCTURE

The final structure (with d = 10 mm and b = 17 mm) is shown in Fig. 5(a). A passive matching network (two capacitors and one inductor) was developed in CST 2018 to match the two ICEs to 50Ω over the frequency band. A T-divider is used for combining the two paths. Fig. 5(b) shows that the operating band is from 0.79 GHz to 2.3 GHz at -6 dB reflection coefficient. Moreover, the radiation pattern is stable and resembles the dipole pattern in the entire operating band. Figure 2(d) shows the current distribution when the final ICE design is excited.

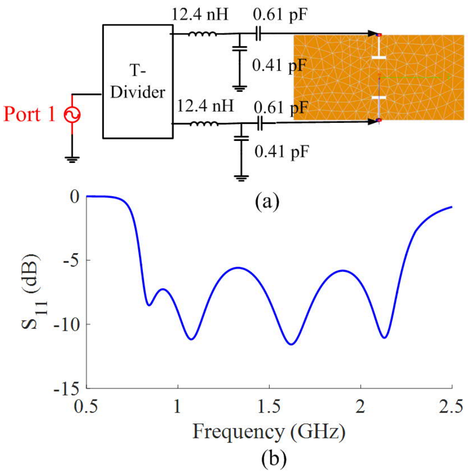

Fig. 5. (a) Final antenna structure with feed network and (b) reflection coefficient S_{11}.

IV. CONCLUSION

In this paper, the systematic design of ICEs for the excitation of a rectangular terminal chassis is described. Two ICEs consisting of T-shaped slots are used as a probe to purely excite the fundamental dipole mode of the chassis. The key dimensions of the ICEs were identified using CMA and bandwidth potential, and then optimized to achieve a large impedance bandwidth. More analysis on CMA will be provided in the full paper.

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