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Wideband equivalent circuit model for smartphone antennas based on characteristic modes

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Wideband Equivalent Circuit Model for Smartphone Antennas based on Characteristic Modes

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***Abstract*—In this paper, an approach to model the impedance characteristic of a generic smartphone antenna with lumped circuit elements based on characteristic modes is shown. In contrast to a pure fit of simple RLC resonator circuits, a model based on characteristic modes can deliver an enhanced insight into the real physical behavior of the modeled antenna. To obtain such a model, each dominant mode is modeled with a separate circuit. The superposition of all these circuits yields the whole model. To obtain the circuit models, we use an approach based on high pass circuits of even order, which is extended so that it is valid for inductive modes, too.**

I. Introduction

Antenna design for current mobile handsets becomes more and more challenging. These antennas have to cover a brought range of frequency bands while providing enough bandwidth for modern high data rate applications. The occupied volume of smartphone antennas has to be very low, while the shape is primarily influenced by esthetic design considerations.

As stated in [1], the traditional concept for mobile device antennas is to use self-resonant types. Often, this leads to a complex structure. In contrast, the design influenced types used in modern smartphones are typically antennas based on capacitive coupling elements (CCEs). This antenna principle, which is basically non-resonant, is used to excite the wave-modes of the entire smartphone chassis. Therefore, in contrast to the traditional point of view, the whole mobile device acts as its antenna. This relationship between coupling element and chassis has been analyzed in [2] based on coupled RLC equivalent circuits.

As shown by Adams [3], this is not an optimal choice. In order to get more accurate results with the benefit of a standard modeling procedure, it is advisable to use an approach based on characteristic modes. An additional advantage of this approach is an equivalent circuit model (ECM) that is based on the real physical behavior of the fundamental modes so that it is directly connected to the modal radiation pattern.

II. Circuit models for modal admittances

The input admittance Y_{in} of an antenna at feedpoint p, whose feed can be described as a gap voltage source, is [3]

$$Y_{\text{in}}[p] = \sum_n Y_{n,p} = \sum_n \frac{J_n^2[p]}{1 + j\lambda_n}, \tag{1}$$

with eigenvalues λ_n and modal currents $J_n[p]$. The quantity

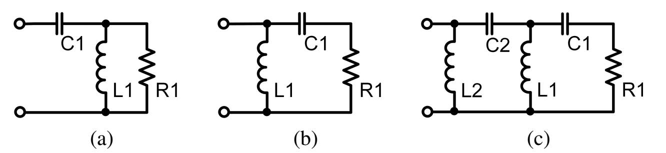

Fig. 1. High pass equivalent circuit models. (a) Second order capacitive high pass (HP2-CAP). (b) Second order inductive high pass (HP2-IND). (c) Fourth order inductive high pass (HP4-IND).

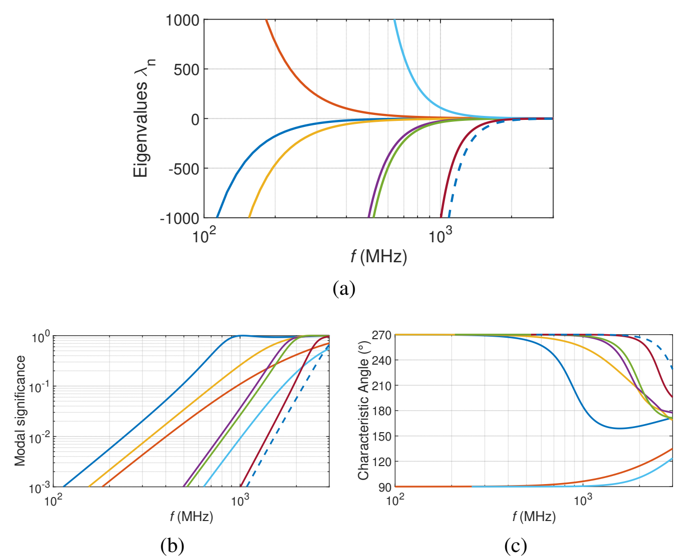

Fig. 2. (a) Eigenvalues, (b) modal significance and (c) characteristic angle of a 130x70 mm^2 thin PEC plate.

$Y_{n,p}$ is the modal admittance of mode n at position p. The sum of all modal admittances is the input admittance Y_{in}, but in order to get a suitable approximation of Y_{in} it is possible to reduce the sum to contain only those modes that have got a strong coupling with the chosen feed, determined by $J_n[p]$.

In order to create an ECM for an antenna, the modal admittance of each dominant mode has to be modeled with an equivalent circuit separately. As shown in (1), the input admittance Y_{in} is calculated as sum of all modal admittances $Y_{n,p}$, i.e. as a parallel connection of all equivalent circuits. To realize these circuits, we adopt an approach introduced in [3], which uses high pass circuits of even order, exemplarily shown for a second order capacitive high pass in Fig. 1(a). In [3], this approach shows a good fit for the first modes of

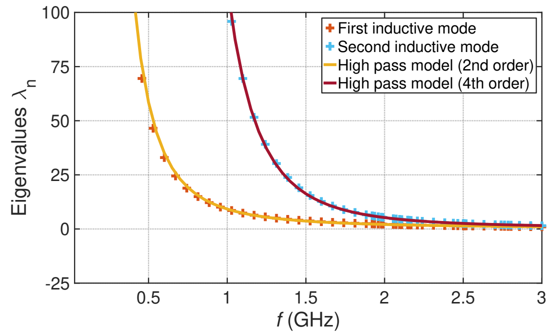

Fig. 3. Eigenvalues for inductive modes of a thin PEC plate compared to circuit models based on inductive high passes.

the investigated center-fed thin dipole. In order to obtain an ECM for a smartphone antenna, we begin with an investigation of a 130x70 mm^2 thin perfect electric conductor (PEC) plate, which represents the chassis of a common smartphone.

All modes of this model are computed with an in-house software tool based on MATLAB. In Fig. 2(a), the eigenvalues of the first eight modes of this plate are depicted. It can be seen that there are, in addition to the capacitive modes known from dipole investigations, two modes with entirely positive eigenvalues. These inductive or "special non-resonant modes" [4] need a different equivalent circuit because of their positive eigenvalues, which leads to a different slope in the characteristic angle [4], shown in Fig. 2(c), while the shape of modal significance [4], as seen in Fig. 2(b), remains comparable for both types of modes. Therefore, for this kind of modes a similar high pass equivalent circuit is needed which behaves inductively instead of capacitively. This circuit is depicted, exemplarily for second order, in Fig. 1(b).

With this, it is possible to model the inductive modes of the PEC plate, which is shown in Fig. 3. The first inductive mode is modeled with a second order inductive high pass (HP2-IND) whereas a fourth order inductive high pass (HP4-IND, Fig. 1(c)) is used for the second inductive mode. The order used is determined from the slope of the modal significance at low frequencies.

III. Application to a Smartphone Antenna Model

As a prove of concept for the above mentioned modeling approach, a model of a generic smartphone antenna has been designed. This model, depicted in Fig. 4, consists of a case with dimensions equal to the previously analyzed PEC plate (130x70 mm^2), a capacitive coupling element (7x70 mm^2) and a port, modeled as a gap voltage source, positioned at an offset of 4.25 mm from the middle of the gap between chassis and coupling element to realize an antenna matched to 50 Ω.

The results of the modal analysis of this structure are used to identify the modes that contribute most to the antenna input admittance, which depends on low eigenvalues λ_n and high modal currents $J_n[p]$. This leads to three dominant modes, which are all modeled with ECMs. The superposition of all equivalent circuits and, for reference, of all modal admittances used to create these circuits, is computed by (1). For comparison, the input impedance of the antenna, which is, in fact,

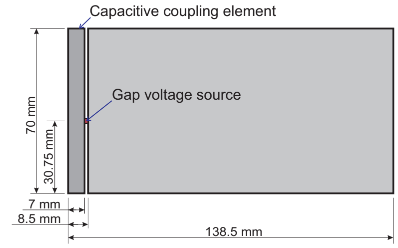

Fig. 4. Model of a generic smartphone chassis with a capacitive coupling element and a gap voltage source.

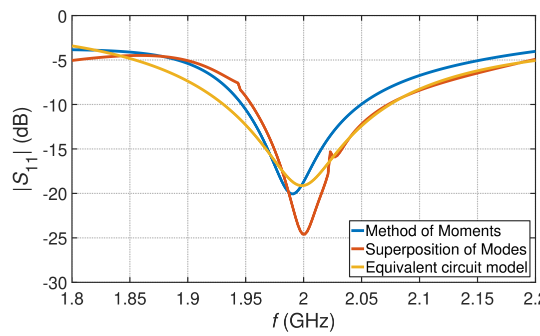

Fig. 5. S_{11} of a smartphone antenna compared to the superposition of dominant modes and an equivalent circuit model.

the inverse of the superposition of all modal admittances, is computed by the method of moments (MoM). The results are shown as input reflexion coefficient, referenced to 50 Ω, in Fig. 5. Our equivalent circuit model is in good agreement with the reflexion coefficient computed by MoM, which proves the applicability of this modeling approach.

IV. Conclusion

It has been shown that it is possible to develop an equivalent circuit model for a generic smartphone antenna model based on the theory of characteristic modes. An existing approach, mainly based on studies on a simple dipole, has been extended to include so called "inductive modes", which is necessary to deal with antenna structures that are common in current mobiles. The applicability of this approach has been demonstrated with a simple phone model, which shows a good agreement between ECM and the results gained from the method of moments, even if only the three most dominant modes are taken into account.

References

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