Characteristic Mode Analysis of Smart Phone Antenna using HW FEKO

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Abstract **– In this paper, characteristic modes involved in smart phone are analyzed using the available CMA code in the comprehensive 3D electromagnetic field solver HW (HyperWorks) FEKO. A typical design workflow of characteristic mode analysis is considered to meet design specifications. It includes investigation of the structure, excitation of the correct modes, and verification of the design parameters. Taking this design workflow into consideration, a design example of a smart phone antenna involving ground plane and frame at GSM 1800 band is proposed. The selective mode excitation and tuning the modes using resonators, grounding points and slots are used in the simulation to obtain broadband characteristics and acceptable radiation pattern.**

Index Terms **— Characteristic Mode Analysis, smart phone, FEKO, CMA.**

1. Introduction

Characteristic modes are defined as real current modes, which can be calculated numerically for arbitrary shaped conducting bodies. These modes, or closely defined as characteristic currents, can be obtained as the eigenfunctions of a particular weighted eigenvalue equation, as derived in [1]. Garbacz, et.al proposed the original theory of characteristic mode analysis (CMA) in 1971 [2] and it was later refined by Harrington and Mautz [1]. Due to its advantage of providing physical insight of the antenna operating principles, it is broadly used typically for antenna design and antenna placement.

However, calculation of these orthogonal current-modes requires an expensive computational resource in terms of both runtime and memory usage since the eigenvalue equation is derived from the dense Method-of-Moments (MoM) impedance matrix. HW FEKO [3] introduces an efficient solution technique based on an iterative eigensolver approach to calculate only the part of the spectrum that is required. For the reason of further reducing the simulation runtimes, distributed and shared memory parallel programming models as well as GPU acceleration have also been integrated with the CMA [4].

This paper considers alternative design approach to excite specific modes to obtain desired performances of broadband and acceptable radiation pattern. The method of mode excitation concepts proposed in [5] is used as a design reference. The design approaches introduce capacitive elements, grounding pin, slot and quarter-wavelength passive resonator to select the appropriate modes involved in the ground plane and frame of smart phone. The introduced methods of capacitive elements, grounding pin, slot show that the proposed design approaches can have a broadband over the intended center frequency band of 1.8 GHz with acceptable far-field radiation pattern and total radiated power (TRP). In addition, quarter-wavelength passive resonator is suitable for narrow-band application.

2. CMA Background Approach

Derivation of the following particular weighted eigenvalue equation is explained in detail in [1]. Characteristics modes are the eigenfunctions of the following equation [1].

$$X(\vec{J}_n) = \lambda_n R(\vec{J}_n) \quad (1)$$

where λ_n are the eigenvalues, $\vec{J}_n$ are the eigencurrents, R and X are the real and imaginary parts of the impedance operator, respectively. Since the impedance operator is the results of integrodifferential equation, it can be expressed in the following Hermitian parts as,

$$Z = R + jX \quad (2)$$

where R and X are real and symmetric operator. The characteristic modes calculated by solving (1) are real and orthogonal functions and depend only on the shape and size of the conducting body.

3. CMA Design Workflow

CMA design workflow is ideally required to meet the design specifications. It typically includes three major steps i.e. initial investigation of the structure, excitation of the correct modes, and verification of the design parameters. As the initial step, one only needs to select a simple representative structure for the model without considering any excitation to fully understand the structure. The simple representation of the structure may refer to the following considerations i.e. removing dielectrics, modelling metal as surfaces. The important result of which modes are resonant and at which frequencies are the resonant ($\lambda = 0$, MS = 1, CA = 180°) can be extracted at this stage. If there is a specific design requirement in modal current distribution, field distribution, or radiation pattern, it would be beneficial to investigate such requirements either with a single mode or combine modes at this particular stage.

Following the structural investigation, an excitation of the correct modes is another important consideration. A feed placement and arrangement of amplitude and phase can be selected to couple to the desired modes. One needs to ensure that unwanted modes are not excited in addition to the desired modes. It can possibly be carried out through analyzing the modal excitation and weighting coefficient. The final step of the workflow is the verification of the CMA design. It includes a final modification of the structure, feed location, amplitude and phase. One may revert the structure to a realistic model which consists of dielectrics and metal thicknesses. If design specifications were not met, the previous step of defining the modal excitation can be repeated until the expected results are achieved.

4. Simulation Design Approach of Antenna in Smart Phone

The earlier design approach of antenna design in smart phone focusing at low-band frequency with less resonant modes has been discussed in [6]. The current approach is focused at the GSM high band of 1.8 GHz. Based on the method proposed in [5], quarter wavelength resonator is integrated into the frame of which the capacitive element excites the dominant modes. The modal current distribution of the design is shown in Fig. 1

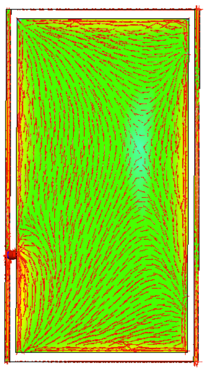

Fig. 1. Modal current distribution of mode 7 (which is resonant at 1.8 GHz) for the quarter wavelength resonator integrated into the frame.

Broadband performance and total radiated power of this design (design 1) is referred as a design goal for the alternative design approaches of using grounding points, slots, and gaps to select the intended modes. Fig. 2 shows the S11 of all the design approaches. A half wavelength resonator (original), half wavelength resonator with ground pin, half wavelength resonator with slots are referred to design 2, design 2+, and design 2++, respectively while design 3 is referred to a passive quarter wavelength resonator integrated into the lower part of the frame. It is obviously shown that design 2, design 2+, and design 2++ have broadband characteristics. On the other hand, design 3 is specifically beneficial for narrow band application.

The ground pin in design 2+ has a function to suppress an anti-resonance of mode 1 of the design 2 (original) while the slots are introduced to suppress mode 4 of the design 2 (original) resulting in improved overall performance. Design 2 also has the advantage of being easily extendable to also operate at 900MHz. The acceptable radiation pattern of all the design approaches at 1.795 GHz are shown in Fig. 3.

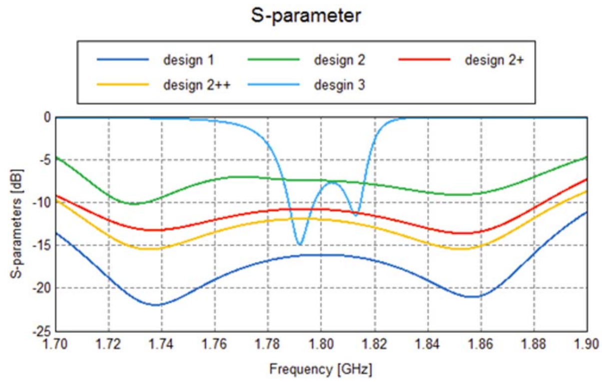

Fig. 2. S11 of the design approaches.

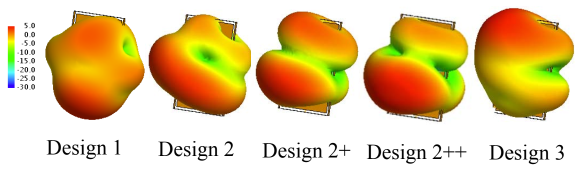

Fig. 3. 3D radiation pattern of the design approaches.

5. Conclusion

Characteristic mode analysis (CMA) can be used to broaden the understanding of antenna performance including modal current and modal radiation pattern. The bandwidth of the resonant modes has a strong correlation to the actual antenna bandwidth. It is also interesting to note that it is more challenging to isolate a single mode when multiple modes are resonant, especially if only a single excitation point is available.

References

[1] R. F. Harrington and J. R. Mautz, “The Theory of Characteristic Modes for Conducting Bodies,” IEEE Transactions on Antennas and Propagation, vol. 19, no. 5, pp. 622–628, 1971.

[2] R. J. Garbacz and R. H. Turpin, “A generalized expansion for radiated and scattered fields,” IEEE Transactions on Antennas and Propagation, vol. 19, no. 3, pp. 348–358, 1971.

[3] HyperWorks FEKO 14.0, Altair Engineering Inc., http://www.altairhyperworks.com/product/FEKO

[4] D. J. Ludick, E. Lezar, and U. Jakobus, “Characteristic mode analysis of arbitrary electromagnetic structures using FEKO,”in Proc. International Conference on Electromagnetics in Advanced Applications (ICEAA), 2012, Cape Town, South Africa, pp. 208 – 211.

[5] R. Martens, et al., “Inductive and Capacitive Excitation of the Characteristic Modes of Small Terminals”, Loughborough Antennas & Propagation Conference, 2011, Loughborough, England, pp.1 – 4.

[6] P. Futter, et al., “Simulation Approach for MIMO Antenna Diversity Strategies”, EDICON 2015