Equivalent Circuit Modeling of Monopoles on a Small Platform

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ABSTRACT: Monopole radiators on finite ground planes may be used as elements of phased array antennas. A part from mutual coupling of array elements, the coupling to the current modes on the ground plane ("chassis modes") has to be considered. The paper presents an investigation of the excitation of the first two chassis modes by a monopole radiator at two positions on a small rectangular ground plane. The effects of chassis mode excitation in the radiator impedance and radiation patterns are presented as well as the current distributions on the ground plane. A resonator-based equivalent circuit is shown to model closely the full-wave simulations and allowing the calculation of radiation contributions from the radiator and the chassis modes.

INTRODUCTION

Experimental investigations of radiation patterns and mutual coupling of monopole (MP) elements on electrically small ground planes [1] have indicated the excitation of current modes on the ground plane ("characteristic modes" or "chassis modes"). Ref. [2]-[5] present modeling of coupling of various types of antennas with chassis modes using the concept of coupled resonators and mostly focusing on the effect of bandwidth enhancement. With a view to the analysis of a two-element phased array of MP radiators, this contribution starts to explore the excitation of the two lowest order chassis modes by MP radiators on a small rectangular ground plane and develops an equivalent circuit model for the MP radiator and its coupling to the chassis modes. Based on this, a later paper will present the modeling of mutual coupling between two MP radiators including the coupling to the chassis modes.

CHASSIS MODE EXCITATION BY MONOPOLE RADIATOR

Fig.1 shows the geometry of a quarter-wavelength monopole for 2.45 GHz mounted at the center of a 100 mm x 40 mm ground plane. The dashed monopole indicates a second position at the middle of the short edge with a distance of 7 mm from the edge. Resonant frequencies and respective quality factors for the (thin) chassis were calculated in [6]. The first two modes correspond to the half-wave and the full-wave dipole modes along the major chassis axis, as indicated in Fig.2, and resonant frequencies of 1.26 GHz and 2.68 GHz are given with Q-factors of 2.3 and 3.0 respectively.

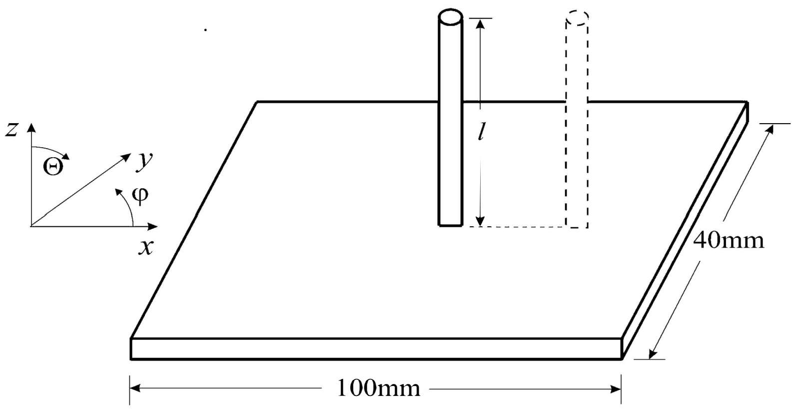


Fig.1: Quarter-wavelength monopole on small ground plane. Monopole length l=27.5 mm and monopole radius r=1.2 mm.

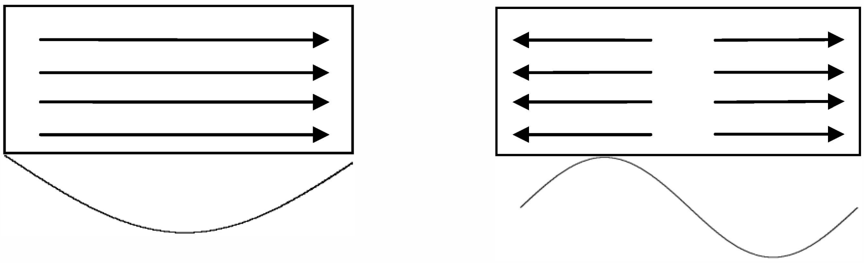
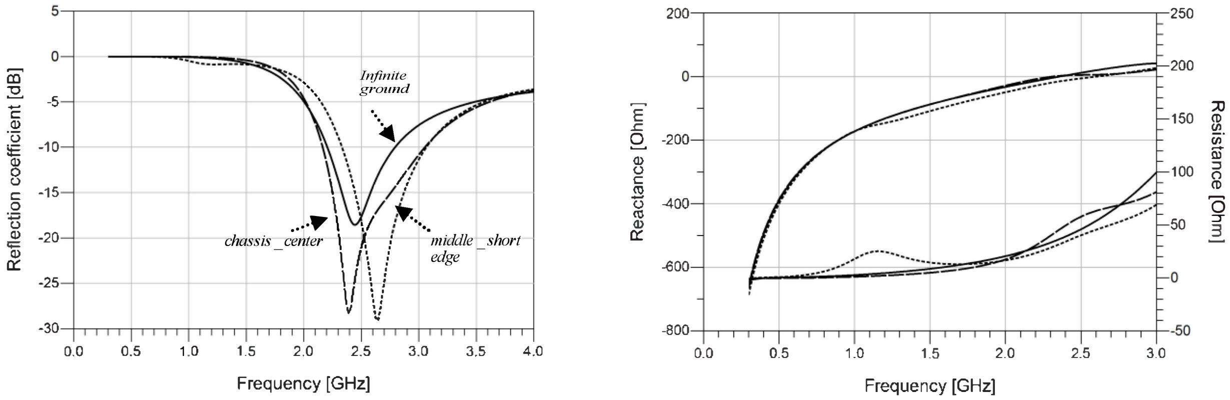


Fig.2: Current schematics for the half-wave (left) and full-wave (right) modes of the major axis of 100 mm x 40 mm chassis.

The effect of chassis mode excitation can be observed in the MP impedance frequency variation calculated by a full-wave simulator (EMPIRE), Fig.3. It is seen that the MP resonant frequency changes as a function of position on the chassis and some change in bandwidth can be observed. However, more interestingly, we note deformations of the plots of reflection coefficient and impedance components over frequency at or close to the resonant frequencies of the chassis modes. In particular, the MP radiator at the chassis center is seen to couple to the second mode around 2.5 – 2.8 GHz where the resistance part peaks. No coupling is seen in this case close to the first chassis mode frequency around 1.2 GHz. This mode is excited by the MP at a position in the middle of the short edge, as we see a distinct peak in the resistance. In both cases, the chassis modes have less effect on the reactance part of the MP impedance than on the resistance, which may be explained by the high Q-factor of the MP compared to the chassis modes and the low radiation resistance of the MP (at least below quarter-wave resonance). The characteristic surface current distributions on the chassis for the two MP positions are shown in Fig.4. The centered MP excited at 2.45 GHz creates a distribution which is perfectly anti-symmetric w.r.t. the center y-z-plane and which can be realized as the superposition of the MP currents and the anti-symmetric second chassis mode. On the other hand, the MP positioned at the middle of the short edge, when excited at 1.2 GHz creates a pattern which can be realized as the superposition of the MP currents with a strong contribution from the symmetric first chassis mode.



(a) (b)

Fig.3: (a) Reflection coefficient and (b) input impedance of the simulated MP at the chassis center and at the middle of the short edge of the chassis compared to MP on infinite ground plane.

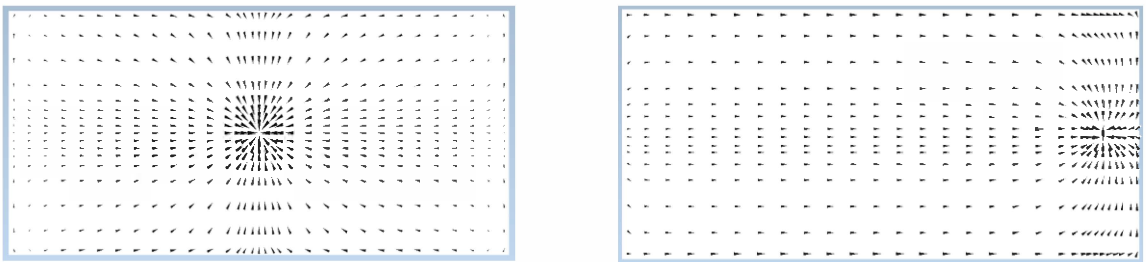


Fig.4: Current distribution for MP at the center (2.45 GHz) and at middle of the short edge of the chassis (1.2 GHz).

The effects of chassis modes on the MP radiation pattern for both positions are seen in Fig.5: The monopole at the middle of the short edge greatly fills the MP pattern null along the z-axis at 1.2 GHz and still at 2.45 GHz provides some filling, while the polarization of the radiation at $\theta = 0°$ and 180° is x-directed. This clearly indicates the excitation of the first chassis mode. On the other hand, the MP at the chassis center exhibits no filling, which proves that the first mode is not excited; only the second chassis mode is excited in this position which leads to pattern distortions in the x-z-plane while the MP pattern is undistorted in the y-z-plane where the second chassis mode radiation exhibits a null. Moreover, the patterns support the observation that the first chassis mode is resonant at or near 1.2 GHz while the second is at or near 2.45 GHz.

To improve an overall understanding of the effect of chassis modes, an equivalent circuit model was developed employing series and parallel RLC resonators. Based on [7], a series RLC resonator is used to model the monopole mode. Consequently, a parallel RLC resonator is used to model the chassis modes [4]. The resonant frequencies and corresponding quality factors calculated in [6] are used in the design of the equivalent circuit as initial values. As the electrical length of the chassis increases due to implementation of the MP element on the chassis, its resonant frequency reduces [2]. Optimization goals in a circuit model include conditions on the resonant frequencies and *Q*-factors of both monopole and chassis modes as well as good agreement between EM-simulation and circuit simulation using the Advance Design System (ADS) simulator. In the case of single MP, the coupling to the chassis modes is modeled as an ideal transformer [3], Fig.6. Good agreement between results for the MP impedance from EM and circuit simulation has been achieved as shown in Fig.7. The resonator properties resulting from the optimization process are given in Tab. 1.

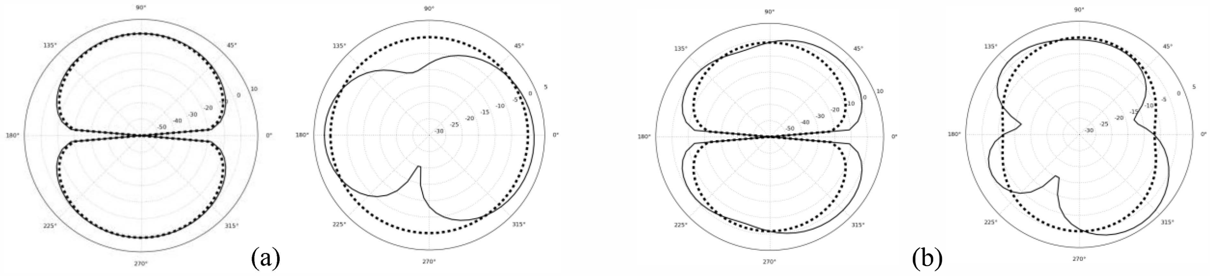


Fig.5: Elevation pattern (—— $\varphi = 0°$ and **....** $\varphi = 90°$) for (a) 1.2 GHz and (b) 2.45GHz of a monopole at the chassis center (left) and at middle of the short edge (right). Note: the right half of patterns represents the upper hemisphere.

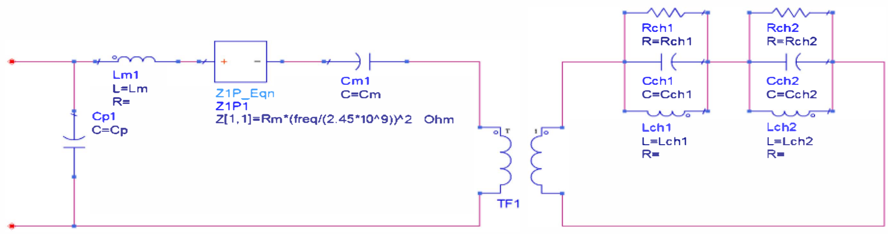


Fig.6: Equivalent circuit model of single monopole on a chassis.

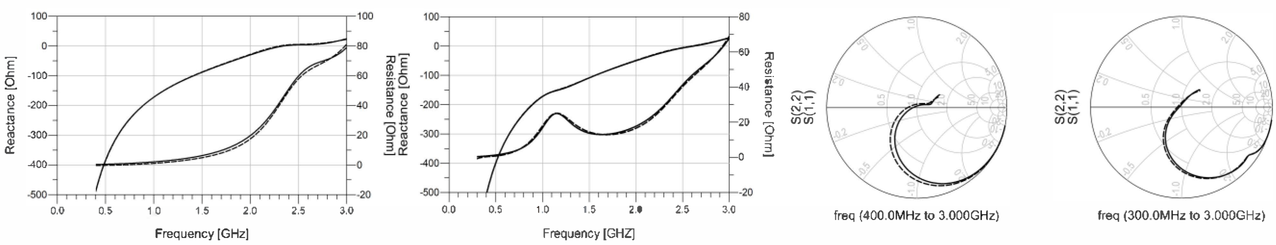


Fig.7: Input impedance of MP at chassis center (left) and at middle of short edge (right) (----- EM simulation and ____ADS simulation).

Tab. 1: Resonant frequencies and *Q*- factors for loaded and unloaded chassis.

Chassis modes	Loaded chassis				Unloaded chassis	
	Resonant frequency GHz		*Q*-factor		Resonant frequency GHz	*Q*-factor
	Center	Middle short edge	Center	Middle short edge		
1st chassis mode	-	1.15	-	2.54	1.26	2.3
2nd chassis mode	2.64	2.62	2.69	2.97	2.68	3

From the circuit model, contribution to total radiation for monopole and chassis modes can be calculated as shown in Fig. 8. The radiation from the MP at the center of the chassis is vastly enhanced by radiation from the second chassis mode which contributes up to 60% of the total radiation around 2.5 GHz; however, no radiation comes from the first chassis mode due to the symmetric arrangement. Up to 90% of total radiation is due to the first chassis mode for the MP at the middle of the short edge around 1.2 GHz, while around 32% of total radiation is due to the second chassis mode at around 2.5 GHz where the major part still comes from the monopole antenna at its resonant frequency. Based on the calculation of radiated power contributions above, and analyzing different positions of the MP along the major axis of the chassis, it is possible to evaluate the coupling to the chassis modes as function of position, Fig. 9. It is seen that the central MP couples strongly to the second chassis mode while coupling to the first mode crosses zero and increases steadily towards the two edges of the chassis. On the other hand, the coupling to the second mode increases again after going through a minimum close to the edges. This behavior is also reflected in the resulting relative bandwidth of the MP.

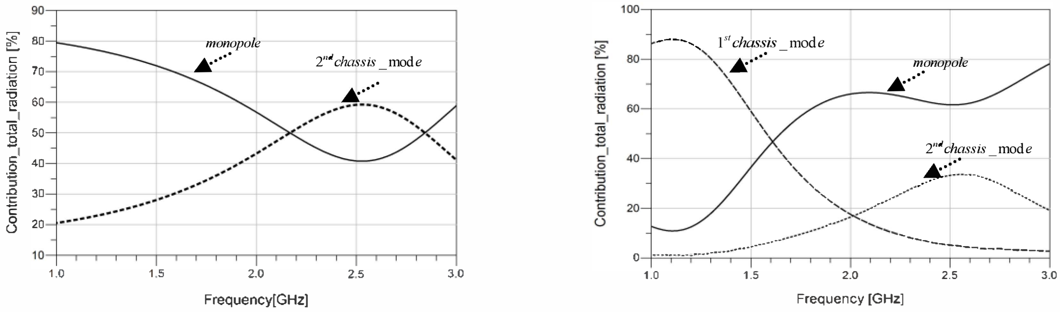


Fig.8: Contribution to total radiation for MP at center (left figure) and MP at middle of short edge (right figure).

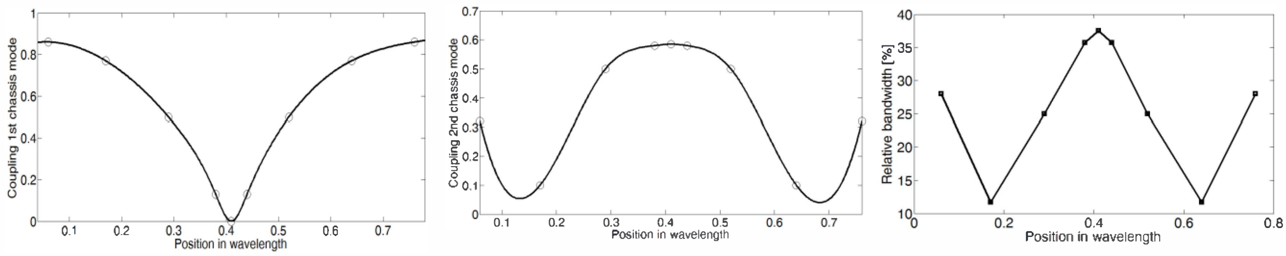


Fig.9: Coupling of the MP to the 1st chassis mode, to the 2nd mode and resulting relative bandwidth at 2.45 GHz.

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