Non-resonant Element in Slotted Ground Plane for Multiband Antenna Operation

Cristina Picher, Jaume Anguera, Aurora Andújar, and Adrián Bujalance

New ways of achieving small, multiband, multifunctional, and standard solutions for mobile handset antennas are demanded in the current wireless market. A non-resonant element of 5 mm × 5 mm × 5 mm, a matching network, and a 100 mm × 40 mm slotted ground plane are proposed to satisfy mobile market demands that require multiband operation and small antenna solutions. The main advantage of the proposed design is that with only one non-resonant element of considerably small size (0.015λ, 900 MHz), the handset is capable of providing operation at mobile bands.

Keywords: Handset antennas, multiband, slotted ground plane, internal antenna, matching network, mobile.

I. Introduction

Apart from studying the geometry and topology of a handset antenna, other lines of research have been more focused on the ground plane due to the important role it plays in the radiation process in terms of bandwidth and efficiency [1]–[9].

As demonstrated in [1]–[5], the antenna bandwidth can be improved by changing the length of the ground plane. Knowing that the main contributor to the radiation at low frequencies (900 MHz) is the ground plane, coupling elements can be used to replace the self-resonant antennas [10]. These coupling elements, used to excite modes in the ground plane, have a C-shape along an edge of the ground plane to obtain such coupling.

A different way of exciting radiating modes in the ground plane is to use very simple non-resonant structures having small electrical size, as proposed in [11]–[14]. In [11]–[13], non-resonant elements are used to properly excite modes in the ground plane to obtain multiband performance. These elements are very small in volume — only 125 mm^3. These non-resonant elements are mainly used to excite the radiating modes of the ground plane to obtain an efficient radiating structure able to operate in multiple frequency bands.

In [11], two non-resonant elements distributed along a short edge of the ground plane (one in each corner) were presented. Sometimes, an antenna engineer is faced with several constraints in terms of available area for the antenna or the complexity of the printed circuit board layout. This is why a new configuration that minimizes the required area and simplifies the tracing in the wireless device is needed. In [13], a concentrated architecture using two non-resonant elements located in the same corner was studied. Since they were very close to each other, a different approach in terms of coupling

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was required. Both designs use one element for the low frequency region (around 900 MHz, where communications standards such as GSM850/900 are allocated) and another one for the high frequency region (around 2 GHz, where GSM1800/1900/UMTS/LTE2100 are allocated). This means a total volume of 250 mm^3. In this paper, a multiband performance is fulfilled using only one non-resonant element of 5 mm × 5 mm × 5 mm in a slotted ground plane, which advocates further steps toward miniaturization in the handset antenna field.

This paper consists of four sections, where Section II presents the radiating system suitable for multiband operation in a handset device. In Section III, design of the matching network to provide multiband operation is explained. Section IV presents the experimental results of reflection coefficient and efficiency. Finally, Section V summarizes the paper.

II. Radiating System

The radiating structure of the proposed design consists of a 100 mm × 40 mm ground plane, which is the typical size of conventional bar phones, and a single non-resonant element of 5 mm × 5 mm × 5 mm located in a corner of the ground plane (see Fig. 1(a)). Furthermore, the ground plane includes one open-end slot of 23 mm × 1.5 mm located near to the corner shared by the non-resonant element. Hereafter, the term low-frequency region refers to frequencies close to 900 MHz and high-frequency region refers to frequencies around 1,800 MHz.

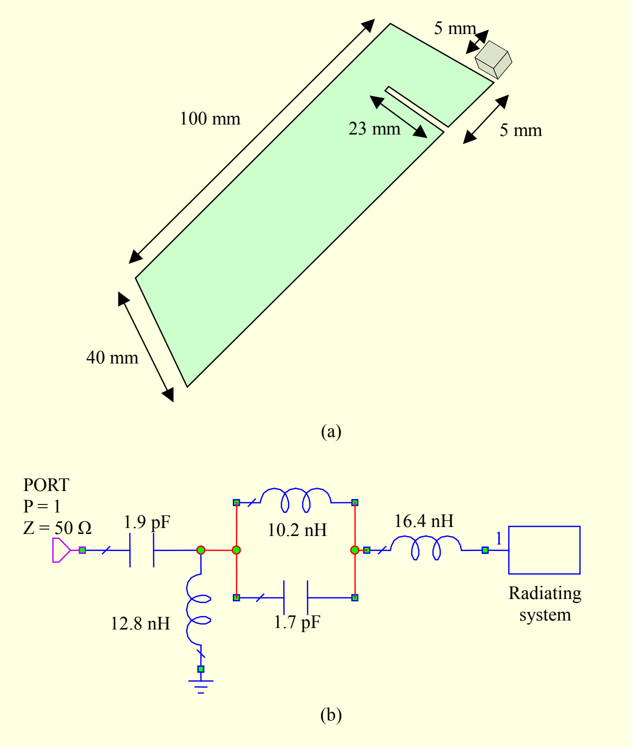

Fig. 1. (a) Proposed radiating system and (b) matching network.

The proposed element is a non-resonant element with very poor stand-alone radiation properties, since it features a high quality factor in each of the target frequency bands ($Q \approx 2250$ at 0.9 GHz and $Q \approx 265$ at 1.8 GHz) [12]. However, its strategic position helps the ground plane mode to be efficiently excited and provides respectable radiation performance. This non-resonant element can be considered as a booster for the ground plane.

The short slot acts as a parasitic element at the high-frequency region. To guarantee effective coupling, the slot should be located close to the non-resonant element and should have the optimum length (approximately $\lambda/4$ at the central frequency of the high-frequency region). Based on a parametric analysis, the slot's length, width, and distance to the feeding point of the non-resonant element are the factors that maximize its performance.

The proposal provides a multiband radiating system featuring satisfactory impedance matching and efficiency, thanks to the combination of the non-resonant element with the slotted ground plane and the proper matching network design.

III. Multiband Matching Network

The general concept of the proposed multiband matching is summarized as follows. Since the non-resonant element presents reactive negative impedance at both the low- and high-frequency region (see Fig. 2(a)), a series inductor is added. This inductor has to bring the reactive part of the input impedance at the high-frequency region to the inductive region, while keeping the low-frequency region in its capacitive zone. Also, the value of the series inductor is adjusted so as to have a similar modulus to that of the reactance (see Fig. 2(b)). After this step, a series inductor is needed to move the impedance in the low-frequency region to the real axis of the Smith chart, and a series capacitor is needed to move the impedance in the high-frequency region to the real axis. Thus, this is carried out by an LC resonator having a resonant frequency between the low- and high-frequency regions (see Fig. 2(c)). On one hand, this resonator behaves as a series inductor for frequencies below the resonance; that is, for frequencies belonging to the low-frequency region. On the other hand, the resonator behaves as a series capacitor for frequencies larger than the resonant frequency; that is, for the frequencies belonging to the high-frequency region. Therefore, after these two steps, both impedances corresponding to the low- and high-frequency regions are located at the real axis of the Smith chart (see Fig. 2(d)). If real parts are not inside an SWR < 3, then a fine-

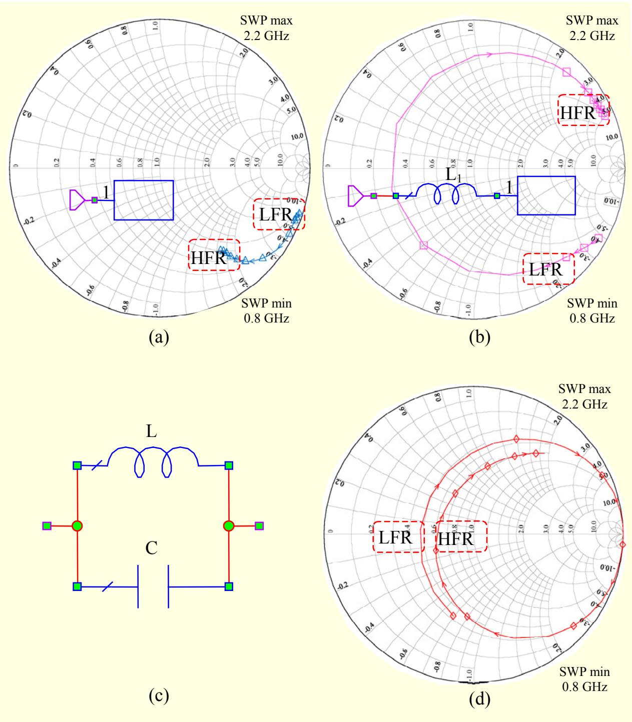

Fig. 2. Multiband matching for a non-resonant impedance having capacitive response at both the low- and high-frequency region: (a) input impedance of radiating system before adding any matching circuit, (b) input impedance after adding a series inductance L_1, (c) an LC resonator, and (d) input impedance after adding the LC resonator after the previous L_1 series.

tune stage can be added.

In accordance with the aforementioned theoretical steps, a multiband matching is designed for the radiating system of Fig. 1(a). The matching network comprises five lumped elements (see Fig. 1(b)). First of all, a series inductance responsible for making the radiating structure resonant at 1.3 GHz is found. As explained before, the purpose of this is to have the low-frequency region and the high-frequency region with opposite sign in their reactive part of the input impedance and for them to try to be in some way conjugate, as explained above. The impedance response seen after the addition of this component is equivalent to an RLC series circuit, with the main particularity being that the low- and high-frequency regions are symmetrically located equidistant from the center of the Smith chart (see Fig. 2(b)). In this case, as the desired resonant frequency is 1.3 GHz, the chosen component is a 16.4 nH inductor. Thanks to the slotted ground plane, an impedance loop located at the high-frequency region appears because of the parasitic effect of the λ/4 slot (see Fig. 3(a)).

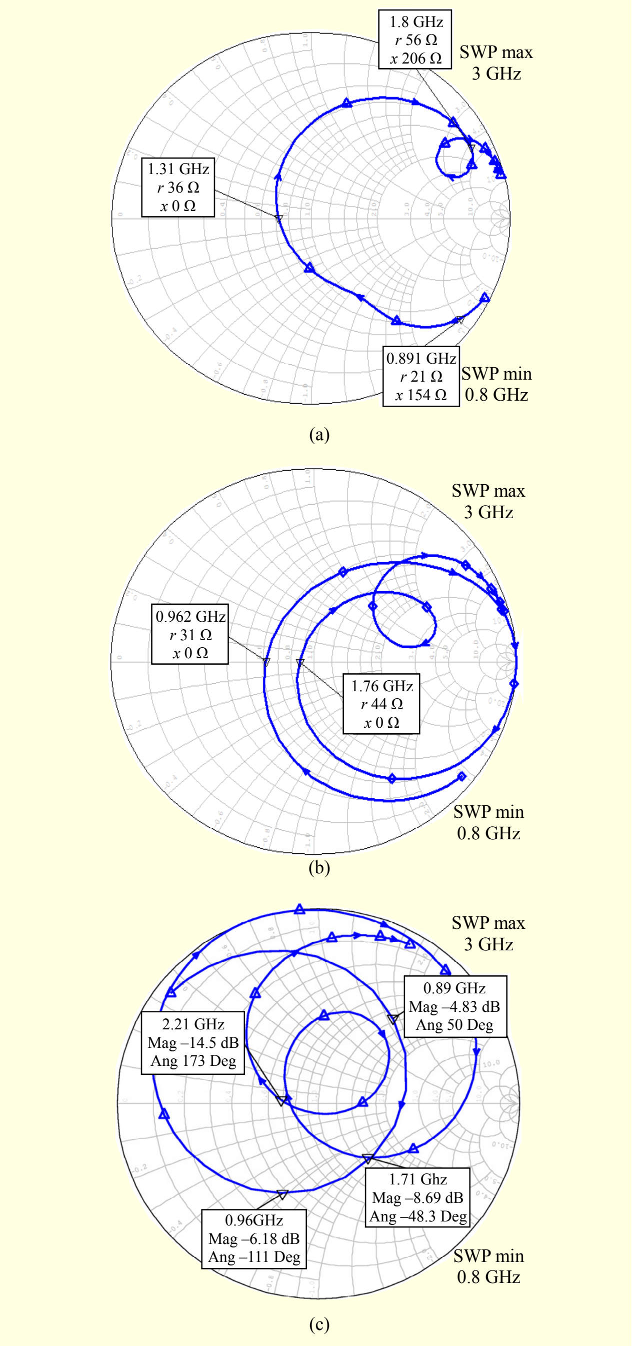

Fig. 3. Impedance of radiating structure and matching network: (a) after series inductance; (b) after adding the filter and the series inductance; and (c) after adding a shunt inductor and a series capacitor to place the impedance loops at the center of the Smith chart.

The second stage of the matching network is a resonant circuit with a resonant frequency at 1.3 GHz (see Fig. 3(b)). As explained before, this resonator moves the inductive impedance corresponding to the high-frequency region to the real axis of the Smith chart (the resonator behaves mainly as a capacitor for $f > 1.3$ GHz). At the same time, the resonator moves the capacitive impedance corresponding to the low-frequency region to the real axis (the resonator behaves mainly as an inductor for $f < 1.3$ GHz). In this case, two RLC series impedances can be observed (see Fig. 3(b)), one resonating at 0.96 GHz and the other resonating at 1.76 GHz.

Finally, a shunt inductor and a series capacitor (acting as a fine-tuning stage) are added to fine-tune both impedance responses, in particular, to place the impedance loop of the high-frequency region at the center of the Smith chart (see Fig. 3(c)). This final step is not always needed.

IV. Experimental Results

Two prototypes (with and without a slot in the ground plane) based on the simulation results have been implemented using 1 mm thick FR4 material ($\varepsilon_r = 4.15$ m, tan $\delta = 0.013$) for the ground plane and a solid cube (5 mm × 5 mm × 5 mm) made of brass for the non-resonant element spaced 1.5 mm form the edge of the ground plane (see Fig. 4). Once the matching network is added, the whole radiating structure provides a bandwidth (SWR $\leq$ 3) of 11.3% in the low-frequency region and 25.2% in the high-frequency region (see Fig. 5). By means of adding this slot, not only can a broader bandwidth be obtained from 1.7 GHz to 2.19 GHz compared to the case of the non-slotted ground plane, but a slight matching improvement can also be observed from 0.834 GHz to 0.934 GHz (see Fig. 5). This happens because this slot enlarges the effective electrical length of the ground plane in the low-frequency region [5].

The measured antenna efficiency using 3D pattern integration with the Satimo Stargate-32 anechoic chamber of the prototype demonstrates respectable radiation performance at both frequency regions. The antenna efficiency in both frequency regions shows better results thanks to the better impedance matching of the slotted ground plane solution compared to the solution in the bare ground plane (see Fig. 6).

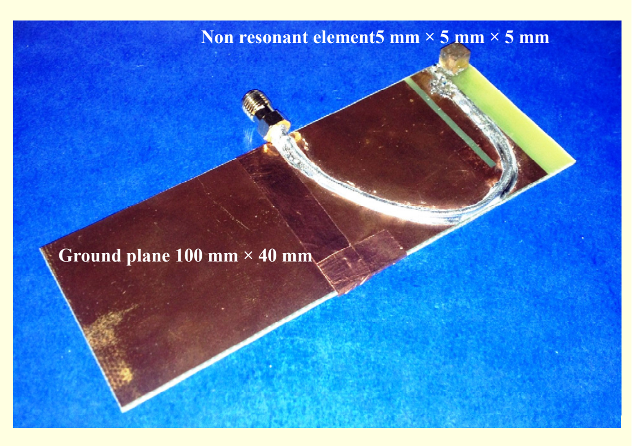

Fig. 4. Fabricated prototype with slot in ground plane.

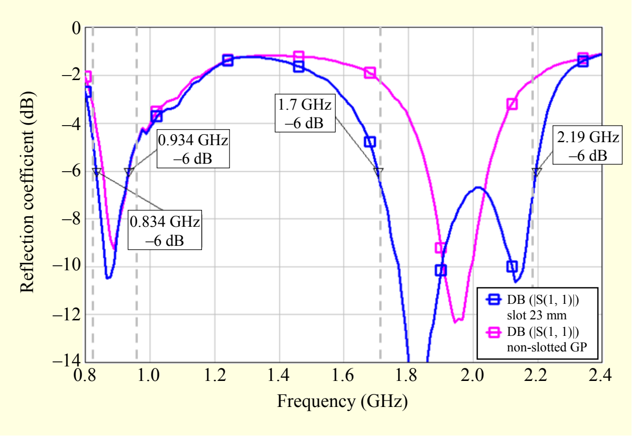

Fig. 5. Radiating system offers a multiband response in two frequency regions, one at the low-frequency region centered at 0.9 GHz and the other at the high-frequency region centered at 2 GHz approximately. Matching network values used for both prototypes (with and without the slot) are shown in Fig.1.

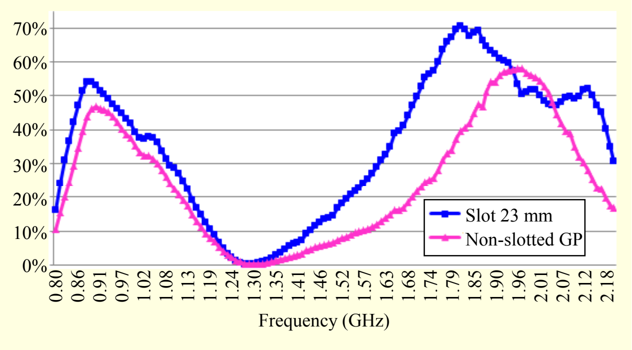

Fig. 6. Antenna efficiency measured in Satimo Stargate-32 using 3D-pattern integration (it takes into account radiation efficiency and mismatch losses). Average efficiency is 47% and 56% in the low- and high-frequency regions, respectively (averaged from the limits shown in Fig. 5).

Radiation patterns that have been measured in the same anechoic chamber and main cuts normalized to the maximum gain ($\varphi = 0^\circ$ and $\varphi = 90^\circ$) and shown at the two representative frequencies of 0.9 GHz and 1.8 GHz, are shown in Figs. 7 and 8, respectively. The proposed radiating system has radiation patterns with low directivity, which is desirable for mobile devices. The measured directivity using 3D pattern integration is 2.6 dB at 900 MHz and 4.1 dB at 1,800 MHz.

Further experiments will consider the effects of the human hand and head, as well as the effects of nearby components. After some previous research with similar technologies, the preferred position to minimize the absorption of radiation to the head is the down position, which is a typical position for current handset antennas [15].

One of the main advantages of the proposed design is that it presents a reduced volume compared to other multiband handset antenna designs that make use of a slotted ground plane [5]–[6]. Concretely, the volume of the required radiating element has been reduced by a factor of 10 with respect to the

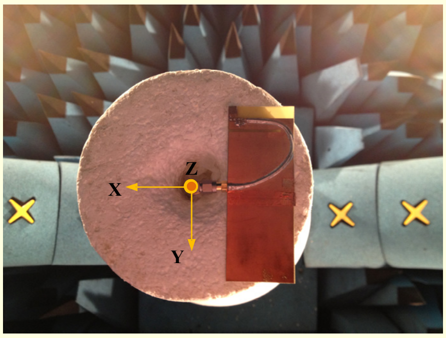

Fig. 7. Radiation pattern measurements in the Satimo-32 anechoic chamber.

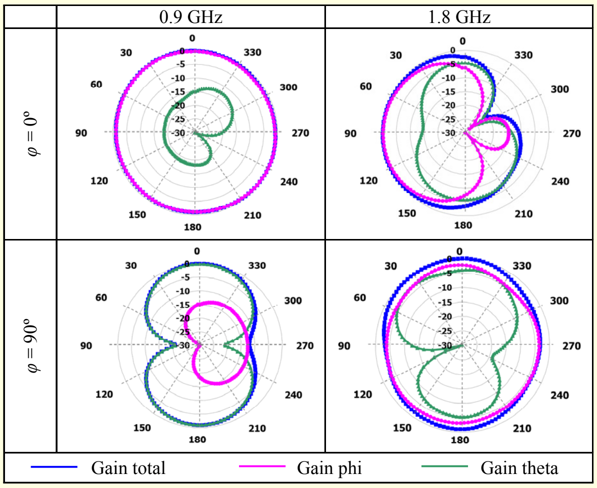

Fig. 8. Measured radiation patterns at 0.9 GHz and 1.8 GHz. The location of the prototype with respect to the coordinate axis is shown in Fig. 7.

typical volume of antennas used in mobile phones [16], which is a huge reduction, and demonstrates the potential of the present proposal.

V. Conclusion

A new radiating structure using a non-resonant element and a slotted ground plane has been presented. The proposed design offers a multiband solution with a single non-resonant element (of size 5 mm × 5 mm × 5 mm), a 23 mm slot (located 5 mm away from the feeding point), and a matching network. Simulation and measurement results show decent radiation behavior. The solution is appealing for emergent technologies, such as LTE, in mobile devices.

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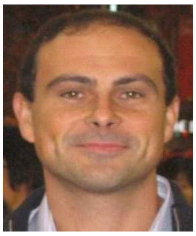

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