Progress In Electromagnetics Research M, Vol. 26, 101–114, 2012

GROUND PLANE CONTRIBUTION IN WIRELESS HANDHELD DEVICES USING RADAR CROSS SECTION ANALYSIS

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Abstract—The ground plane of wireless handheld devices plays a significant role in the electromagnetic behavior determining bandwidth, efficiency, and radiation patterns. Therefore, it is necessary to determine the frequency region where the ground plane can be better excited, especially for low frequencies where the performance of the radiating system is critical due to size limitations with respect to the operating wavelength. A fast method based on the radar cross section (RCS) is presented for computing the frequency at which the ground plane is better excited. The proposal is applied to three typical wireless platforms: a handset phone, a smartphone, and a clamshell phone. The method is compared with characteristic mode analysis and the results demonstrate a very good agreement in the resonant frequency prediction. In addition, complex platforms using metallic strips and slots in the ground plane are analyzed using RCS which gives physical insight into the electromagnetic performance.

1. INTRODUCTION

The ground plane plays a very important role in determining bandwidth, efficiency, and radiation patterns of wireless handheld devices. The significance of the ground plane needs to be better understood to optimize the radio electrical performance according to the specific form factor due to the apparition of more communication standards, especially in the low frequency region such as LTE700, and

Received 17 August 2012, Accepted 11 September 2012, Scheduled 27 September 2012
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to the apparition of more platforms into the scene such as smartphones and tablets.

It has been experimentally shown in [1] that for a PIFA antenna on a ground plane of 40 mm width, the optimum length to maximize the bandwidth is 0.4λ. In this regard, handset antennas operating in the frequency region of 698–960 MHz where some standards are allocated (LTE700, GSM850/900), would require a ground plane length of 144.7 mm (computed at 829 MHz), which is too long for many devices. To solve this size limitation, some authors have proposed mechanisms to electrically enlarge the ground plane by using slots or metallic strips to better excite its radiation mode, and as a consequence, larger bandwidth and efficiency are obtained [2–17].

Owing to the relevance of the ground plane, a fast method to give a physical insight into the ground plane electromagnetic performance is proposed. The method employs the RCS parameter which is used to compute the frequency at which maximum back-scattering occurs. To validate it, three platforms are used for the numerical experiments: a bar-type of 100 mm × 40 mm, a smartphone of 120 mm × 50 mm, and a clamshell (two connected plates of 80 mm × 40 mm). The proposal is validated by comparing the results with those provided by characteristic mode analysis (Section 2). In Section 3, the method is applied to understand the radiation of several handset platforms. Finally, conclusions are given in Section 4.

2. RCS ANALYSIS

The proposed method to compute the resonant frequency of the fundamental mode consists in illuminating the platform of the device by a plane wave impinging from the normal direction. In order to find out the fundamental mode, the polarization of the incoming wave is

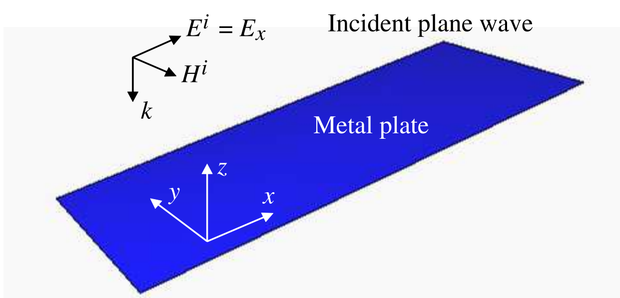

Figure 1. The metal plate is representative of a ground plane associated to a bar-type wireless handheld device.

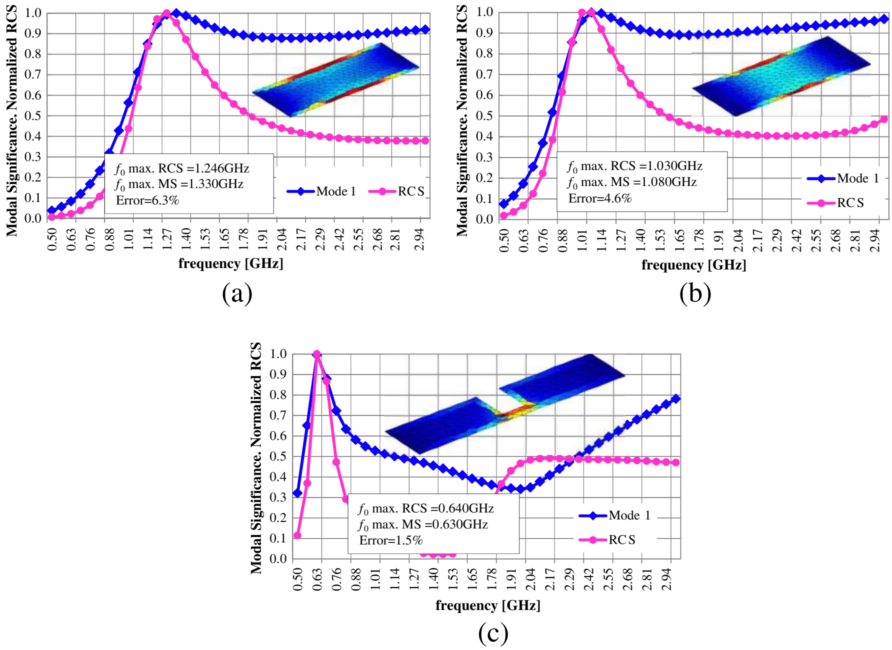

Figure 2. Comparison between normalized RCS and modal significance (MS); (a) bar-type platform 100 mm × 40 mm; (b) smartphone platform 120 mm × 50 mm; (c) clamshell 80 mm × 40 mm for each upper and lower board.

aligned with the longest dimension of the device under test (Fig. 1).

By using a commercial MoM code (IE3D), RCS is computed versus frequency for the aforementioned devices. RCS is normalized in all cases to its maximum value, therefore RCS ranges from 1 to 0 where the maximum value 1 indicates the maximum backscattering which coincides with the better excitation of the metal plate, whereas 0 means transparency, i.e., no scattering is produced by the metal plate (Fig. 2).

In order to validate the method, the first characteristic mode (fundamental mode) has been computed for each platform. The modal significance (MS) parameter is used for comparison purposes. MS ranges from 0 to 1 where 1 means that the mode can be excited in its maximum amplitude [18]. MS is computed using (1) from the eigenvalue λ obtained from the eigenvalue equation [18] using a MoM Matlab-based code [19].

$$MS = \frac{1}{|1 + j\lambda|} \tag{1}$$

As suggested in [18], RCS can be computed as the summation of all characteristic modes supported by a structure. In the present case, the proposed method directly calculates RCS to predict the fundamental frequency at which the ground plane can be excited, therefore only the first characteristic mode (λ_1) is used.

Both RCS and MS have been compared for the three platforms concluding that the prediction of the resonant frequency of the fundamental mode is in good agreement (error less than 6.3% worst case — Fig. 2). It should be pointed out that both RCS and MS agree from the very low frequency region up to the resonance of the fundamental mode. Beyond that, as more modes are excited, RCS and MS diverge. The reason is that some higher modes cannot be excited when the plane wave impinges to the metal plate from the normal direction. Nevertheless, as far as the fundamental mode is concerned, the RCS is a simple and fast method to compute the resonant frequency at which the ground plane of a wireless handheld device can be better excited.

Regarding the obtained results, it is observed how the resonance of the fundamental mode decreases when the ground plane length is larger. For example, for the bar-type platform (Fig. 2(a)), the resonance based on the RCS method occurs at 1.246 GHz while it is 1.030 GHz for the smartphone platform (Fig. 2(b)). This means that an antenna operating in the frequency region given by 698–960 MHz would produce greater performance when integrated in the smartphone platform since the RCS indicates that the ground plane resonance is placed at lower frequencies as will be demonstrated in the practical case of the following section. It is interesting to further note that 100 mm, the typical length of the ground plane of a bar-type platform, results in 0.41λ at 1.246 GHz which is aligned with the experimental results to optimize the bandwidth of a PIFA antenna as demonstrated in [1]. In a similar manner, the 120 mm length of the ground plane of the smartphone platform results in 0.34λ at 1.030 GHz. This less length of the optimum length compared to the one obtained for the bar-type platform may be due to the wider dimension of the smartphone platform, 50 mm versus the 40 mm of the bar-type.

Owing to the clamshell phone in open position, the fundamental mode is highly excited at frequencies around 0.63 GHz (Fig. 2(c)). This result is aligned with aforementioned predictions, since it demonstrates again that the larger the longitudinal dimension, the lower the resonant frequency. This particular platform can be beneficial for integrating antennas operating in lower frequency ranges such as DVB-H (470–700 MHz) antennas for TV reception [20]. For this case, the optimum electrical length computed at 0.63 GHz is now 0.38λ (two times 80 mm plus the 20 mm of the connecting strip).

For all cases, the current distribution associated to the fundamental mode presents the typical half-wave sinusoid behavior, maximum at the center of the metal plate and minimum at the short edges. Such current distribution determines the radiation pattern which presents an omni-directional behavior with a null in the direction of the longest side of the metal plate, i.e., similar to that produced by a half-wavelength dipole. This kind of radiation pattern is usually obtained for wireless handheld devices in the low frequency region where the fundamental mode mainly contributes to radiation.

It is also interesting to note that for frequencies below the frequency of the fundamental mode, the amplitude of both RCS and MS decreases which means that the excitation of the fundamental mode becomes more difficult. This fact, clearly limits the performance of integrated antennas in terms of bandwidth and efficiency below the resonance of the fundamental mode since both the antenna and the ground plane are electrically small.

Finally, ground planes of wireless handheld devices are usually printed on a thin substrate layer of a low-cost material (FR4, 1 mm thick and $\varepsilon_r = 4.15$). The effect of the dielectric coating can also be taken into account by the RCS analysis proposed here. For instance, for the bar-type, if the dielectric coating having the same size as the ground plane is used, the frequency of the maximum RCS shifts from 1.246 GHz down to 1.140 GHz which represents a shift of 8% approximately.

3. APPLICATION

3.1. Ground Plane Size

To validate the usefulness of the RCS method, a non-resonant element of only 5 mm × 5 mm × 5 mm is used to excite two ground planes representative of a bar-type and a smartphone platform as described in the previous section [21–23]. As explained before, the RCS presents larger values in the low frequency region for the smartphone platform resulting at the end in a larger bandwidth of 26.3% (SWR ≤ 3) with respect to the 17.7% for the bar-type platform (Fig. 3).

It is significant to emphasize that since the ground plane is an effective means for radiation, the current antennas such as a PIFA can be substituted by a ground plane booster as the one shown here which at the end, in combination with a radiofrequency system, can perform similar with a much less volume (Fig. 4).

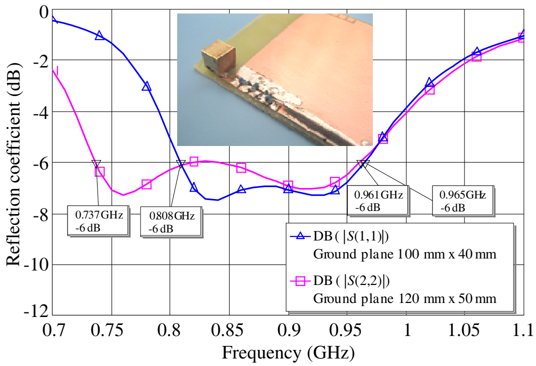

Figure 3. Measured reflection coefficient for a non-resonant element of 5 mm × 5 mm × 5 mm regarding two different platforms.

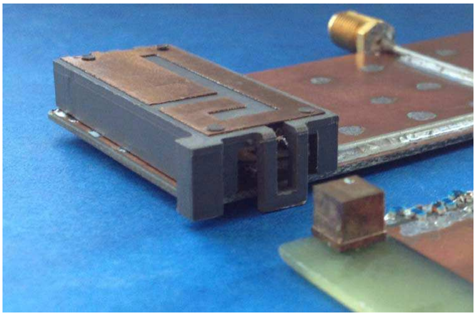

Figure 4. Comparison of a PIFA and a ground plane booster both for GSM850-GSM900 operation. Size for the PIFA is 40 mm × 15 mm × 6 mm whereas the ground plane booster is only 5 mm × 5 mm × 5 mm.

3.2. Enlarging the Ground Plane with Metallic Strips

Another application of the proposed method is useful for analyzing complex platforms. In this sense, a ground plane of 100 mm length presents less bandwidth than a ground plane having 120 mm length as shown before (Fig. 3). In some situations, the ground plane cannot be enlarged due to mechanical requirements given by the phone manufacturer. In those cases, if the bandwidth needs to be improved, some techniques adding intelligence in the ground plane can be used such as for example adding slots in the ground plane [2–12] or adding metallic strips [13–17]. As an example, the proposed method is used here to give a physical insight into the behavior of adding metallic strips to a ground plane having 100 mm length (Fig. 5).

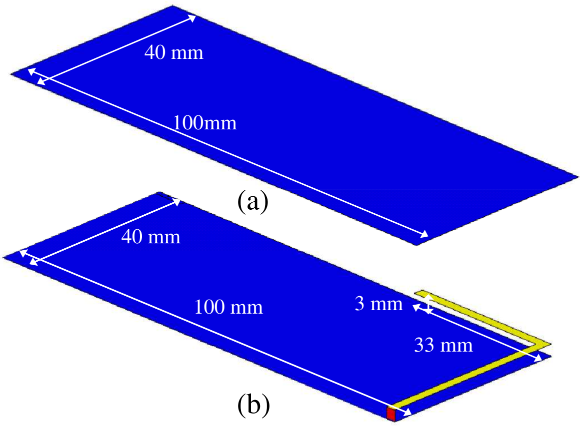

Figure 5. (a) A ground plane of 100 mm × 40 mm and (b) the same ground plane having a metallic strip of 40 mm + 33 mm and 3 mm height. Both ground planes are supported by a thin dielectric slab of 1 mm thick with $\varepsilon_r = 4.15$.

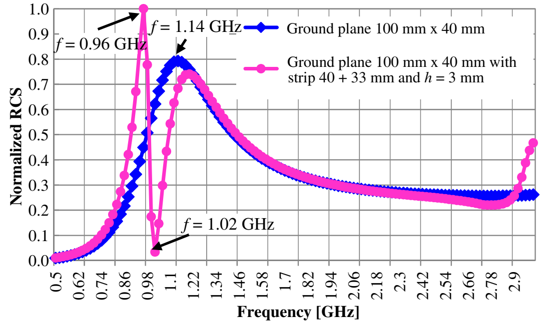

Figure 6. Comparison of the normalized RCS for a ground plane of 100 mm × 40 mm and the same ground plane with the metallic strip as shown in Fig. 5.

For the two ground planes shown in Fig. 5, the RCS is computed according to Fig. 1. For the ground plane having 100 mm × 40 mm, the maximum RCS is found at 1.14 GHz (Fig. 6). For the case with the metallic strip, the maximum RCS is found at 0.96 GHz. Both cases have been normalized to the maximum case which is the ground plane with the metallic strip. Several conclusions can be drawn (Fig. 6):

a) The metallic strip tunes the resonance frequency of the ground plane mode to lower frequencies due to the larger electrical path due to the metallic strip.

b) In the frequency range from 824 MHz to 960 MHz where some communication standards are allocated such as GSM850 and GSM900, the RCS for the ground plane with the metallic strip is larger. Therefore, more impedance bandwidth can be obtained as it is shown next.

c) A minimum of RCS appears at 1.02 GHz for the ground plane with the metallic strip. This null is evidence that the ground plane is not an effective radiator at this frequency. If an antenna in this ground plane operates in such frequency, a poor electromagnetic performance will be obtained as shown next.

From these conclusions, it is interesting to point out that the RCS method gives a physical knowledge in the behavior of not only antennas but in the design of ground planes in order to enhance the performance of handheld antennas. In effect, if the metallic strip were tuned at the central frequency of the frequency region 824 MHz–960 MHz, a null of RCS will appear an thus, a poor performance will occur in said frequency region. Therefore, based on this data, it is clearly shown how the method can be useful to optimize the ground plane design. In this case, it is advantageously used to adjust the length of the metallic strip so as to have a better RCS in the frequency region of interest (824 MHz–960 MHz) while keeping the null of RCS out of the band.

It is interesting to note that the current distribution for the ground plane mode at the maximum of RCS (0.96 GHz — Fig. 6) follows a linear current distribution which at the end determines the typical omni-directional pattern and linear polarization aligned with the long axis of the ground plane of this kind of devices (Fig. 7) [15]. For the null of RCS ($f = 1.02$ GHz — Fig. 6), the ground plane is not an

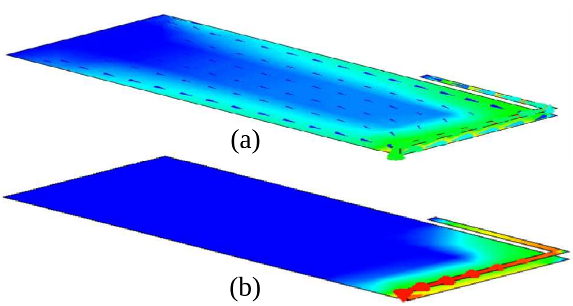

Figure 7. Induced current (A/m) for a plane wave excitation as in Fig. 1 at (a) $f = 0.96$ GHz and (b) $f = 1.02$ GHz. Same maximum and dynamic range is used for both plots.

effective radiator. In fact, at 1.02 GHz, the strip becomes resonating at a quarter of the wavelength (73 mm is approximately $\lambda/4$ at 1.02 GHz). Since the strip produces a current close to the ground plane, the RCS is poor. Therefore, this allows concluding that if an antenna on a ground plane operates at 1.02 GHz, the behavior will mainly depend on the antenna size and not of the ground plane length. This is clearly observed for a PIFA antenna in the ground plane of 100 mm $\times$ 40 mm using the metallic strip (Fig. 8). It is observed that the radiation efficiency (η_r) presents a drop just in the frequency where the RCS presents a minimum since the ground plane is weakly excited and as a consequence, produces poor radiation.

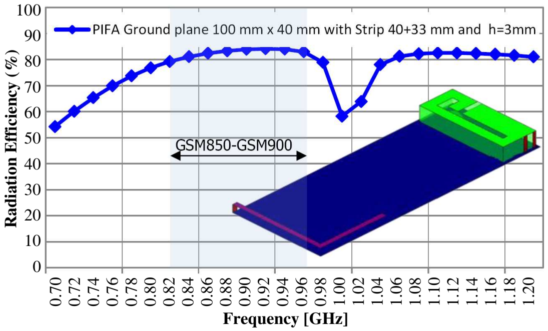

Figure 8. Simulated radiation efficiency for a PIFA on a ground plane 100 mm $\times$ 40 mm and a metallic strip 40 mm + 33 mm and 3 mm height.

Table 1. Measured radiation and antenna efficiency for a PIFA antenna in a ground plane 100 mm $\times$ 40 mm without and with a metallic strip 40 + 33 mm and 3 mm height (Fig. 8). Measurements are obtained using 3D pattern integration with the Satimo Stargate-32 chamber.

	η_r (%)			η_a (%)		
f (MHz)	Without strip	With strip	$\Delta\eta_r$ (dB)	Without strip	With strip	$\Delta\eta_a$ (dB)
820	31.1	38.8	0.96	16.2	23.5	1.62
850	37.5	51.3	1.36	27.1	41.2	1.82
880	39.3	56.0	1.54	33.8	51.6	1.84
890	45.2	65.9	1.64	40.7	62.2	1.84
920	55.4	75.3	1.33	46.7	67.4	1.59
960	62.3	74.0	0.75	44.4	62.0	1.45

Thanks to the RCS analysis, the operation of the metallic strip to enhance the bandwidth in the 824 MHz–960 MHz is better understood: the metallic strip is tuned so as to have the maximum of the RCS in the frequency region of interest while avoiding the minimum of RCS to be in said frequency region. By following this procedure, a PIFA on a ground plane 100 mm × 40 mm having a bandwidth of 8.3% at 900 MHz (SWR ≤ 3) is improved up to 14.6% [15]. Moreover, since the RCS at the frequency region 824 MHz–960 MHz is larger when using the metallic strip (Fig. 8), not only the bandwidth improves but also the radiation efficiency. A larger RCS translates in a better excitation of the ground plane mode when an antenna operates in conjunction with the ground plane and therefore, larger radiation efficiency can be obtained. Better matching and radiation efficiency translates into more antenna efficiency ($\eta_a = \eta_r \cdot (1 - |S_{11}|^2)$). As a brief summary from [15], measured radiation and antenna efficiencies of the PIFA antenna of Fig. 8 with the effect of the metallic strip (Table 1) clearly shows how the radiation efficiency increases around 1 dB across the GSM850-GSM900 frequency region. At the same time, due to a better matching, the antenna efficiency increases almost 2 dB.

It is interesting to point out that the use of metallic strip has been proven not only to be useful for enhancing the bandwidth at the low frequency region but also to provide a robust means for the hand loading [24] and to control the near field for hearing-aid [25]. Therefore, the RCS method becomes an easy tool to give a physical insight which can lead to a better optimization of the metallic strip technique.

3.3. Enlarging the Ground Plane with Slots

Another technique employs slots in the ground plane for enhancing the bandwidth and radiation efficiency of handset antennas [2–12]. The present RCS method is useful for this case to establish a comparison between other methods to enlarge the ground plane as the one having a metallic strip presented in the previous section (Fig. 9).

When properly designed, a slot in the ground plane forces the current to travel a longer path. Therefore, the resonant frequency of the fundamental mode of the ground plane can be shifted to the desired frequency of operation, for instance, to 900 MHz, being this frequency the central frequency of the frequency region comprising GSM850-GSM900 (Fig. 9). Based on the RCS analysis, it is shown how a slot becomes advantageous to tune the resonant frequency of the ground plane mode to 900 MHz. Moreover, this technique does not present a null as it is the case of the metallic strip. However, it may be more challenging to be integrated into a wireless handheld device due to the presence of other components such as a display or a battery.

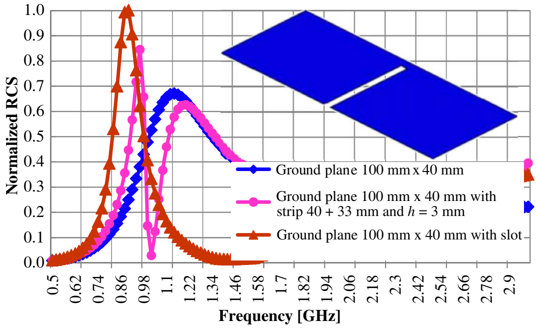

Figure 9. Comparison of RCS for three different ground planes: 100 mm × 40 mm, 100 mm × 40 mm with a metallic strip as shown in Fig. 5, and a ground plane 100 mm × 40 mm with slot 38 mm long and 3 mm width. The plane wave impinges the ground plane as shown in Fig. 1. All ground planes are etched on a thin dielectric slab of 1 mm thick and $\varepsilon_r = 4.15$.

It should be pointed out that the RCS bandwidth is larger for the slot case than the metallic strip (Fig. 9). Thus, one should expect to obtain more bandwidth using a slot in the ground plane rather than a metallic strip. In particular, the bandwidth using the metallic strip is 14.6% for the PIFA in the 100 mm × 40 mm ground plane [15] whereas the same PIFA with a slot in the ground plane [5] has a bandwidth of 35.1% which clearly agrees with the RCS curves of Fig. 9. From a quantitative point of view, it is interesting to link the impedance bandwidth and RCS bandwidth for the two ground planes. Using a -3 dB RCS bandwidth (frequency at which the RCS drops 3 dB), the $\mathrm{RCS}_{-3\,\mathrm{dB}}$ bandwidth for the ground plane with strip and with the slot is 8.0% and 18.0%, respectively. This results in a ratio of 2.25 which agrees with the impedance bandwidth ratio of 35.1% over 14.6% resulting in 2.4. This makes the RCS method useful not only to determine the frequency at which the best excitation of the ground plane mode occurs, but also to estimate the bandwidth of several ground plane configurations.

4. CONCLUSION

A fast method based on RCS for computing the resonance of the fundamental mode of a ground plane has been proposed. The method simplifies the computation of the frequency at which the ground plane of a wireless handheld device can be better excited. This method is suitable for providing a first prediction on the benefits of the ground plane to increase the bandwidth and efficiency of wireless handheld devices.

The proposed method has been also applied to give a physical insight in some enlarging ground plane techniques using metallic strips and slots in the ground plane. In this sense, regarding the metallic strip, when properly designed, the RCS shows a maximum in the frequency region of interest and a minimum at a quarter of the wavelength of the strip. Therefore, this minimum must be placed out of the frequency region of interest. Finally, the RCS bandwidth is related to the impedance bandwidth. In this regard, the technique using a slot in the ground plane has been compared showing that the RCS bandwidth is larger. This ultimately results in a larger impedance bandwidth as it has been shown for a particular antenna placed in the ground plane. The RCS method shows that the slot technique presented here not only presents more bandwidth for handset antenna design but also it has not a minimum of RCS as it is the case of the metallic strip which limits the bandwidth of the solution.

This method helps to a better understanding of the behavior of the ground plane into the electromagnetic performance of wireless handheld devices.

ACKNOWLEDGMENT

The authors would like to thank the Spanish Ministry of Industry, Commerce, and Tourism for their support.

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