Effect of the ground plane in UHF Chip antenna efficiency

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***Abstract*—A study on the effect of the ground plane in a chip antenna efficiency is presented. For the experiment, a chip antenna has been designed to be fabricated in LTCC technology. The size of the ground plane, the clearance area where the antenna is placed and the position of the antenna has been analyzed obtaining their impact in the radiation properties of the antenna. Useful information has been obtained for the design and implementation of small antennas for sub-1GHz application such as ISM bands(868 MHz Eur, and 915 MHz USA) or the new licensed sub-1GHz 5G bands.**

***Index Terms*—antennas, electromagnetics, propagation, measurements.**

I. Introduction

The demand of compact antennas has increased widely due to the environment of all connected devices proposed by the internet of things (IoT) concept. The interconection of all object triggers the inclusion of, at least, one antenna even in small handheld devices, which brings the challenge of the inclusion of a radiating element in such limited space. Specially in the sub-1GHz bands, including new licensed sub-1GHz 5G[1] bands or ISM bands (868 MHz EUR, and 915 MHz USA), the miniaturization is limited due to the well known length limit of a resonating monopole (λ/4).

The most used antennas fabricated in PCB technology, are the inverted F (IFA)[2], and inverted L (ILA) antennas. Both solutions are based on the classic monopole whose performance depends on the scenario where it's placed.

The radiating properties of small antennas are limited, hence the main contribution of their radiation is produced by the ground plane of the connected PCB. The size of the ground plane is critical in terms of efficiency and bandwidth [3]-[6], but also several features must be taken into account such as the size of the clearance, the location of the antenna and possible cancellations due to the distance between the arm of the antenna and the ground plane.

Between 700 MHz-1000 MHz lambda/4 ranges from 7.5 cm to 8.7 cm. For some small devices like a 40 x 25 mm^2 in [7][8] , it's really challenging to fold a monopole, and in these cases, a possible solution is the use of a loaded monopole. This technique consists in placing a coil in between the monopole, either a concentrated element or coiling a section of the wire. At frequencies lower than the resonance of a monopole, its behaviour is capacitive. Therefore, adding a series coil tunes a resonance at lower frequency.

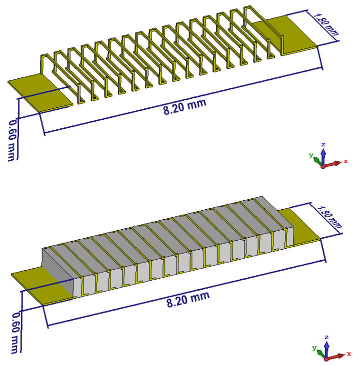


Fig. 1. Designed chip antenna used for the analysis.Top: Ceramic substrate invisible. Bottom: Ceramic substrate visible

In this scenario, several companies such as Johanson[9], Antenova[10] or Fractus[11] propose their chip antennas. It is a recommended solution when an extreme miniaturization is needed.

In this paper a chip antenna has been designed in order to check the radiating contribution of the ground plane connected to the antenna. The chip antenna is based on a loaded monopole to be fabricated it in LTCC technology. This method of fabrication allows the fabrication of multi-layer structures with high precision. The chip antenna consist on a 3D squared coil embedded in a ceramic substrate, including 18 wraps in 8.22 mm. Thus the use of this technology is recommended.

The goal of this paper is to give a insight of the optimum positioning of a small antenna in a PCB and to check the correlation between the ground plane and the radiation efficiency.

II. Chip Antenna design

The chip antenna consists on a coil embedded in a ceramic substrate (Fig. 1). The ceramic material used is a DuPont 9k7 with the electric properties of $\epsilon_r = 7.1$ and $\tan\delta = 0.0009$.

The dimension of the antenna are $8.22 \times 1.8 \times 0.6$ mm and the number of wraps of the coil is 18. With this features the resonance of the coil antenna is centered at 1.4 GHz (Fig. 1) and the calculated inductance is 1 μH.

In order to tune the antenna for the sub-1 GHz bands, a terminal line must be connected in series to the chip antenna controlling the resonance frequency with its length.

A. Position of the load

Loaded monopole antennas have different configurations depending on the position of the load. The current distribution of a monopole exhibits a current maximum at the base of the monopole, and a minimum at the end of the arm(λ/4), thus, coiling the monopole at the base has a higher effect at the size reduction than coiling it in the end. Fig. 2 depicts an example of tuning the antenna with a series terminal line. Both designs are equivalent in terms of resonance (f_o=1.1 GHz), but in the case of the load at the base, the total length of the antenna is smaller.

Due to miniaturization reasons, this paper presents a configuration where the chip antenna is connected to the feeding. Then, the antenna is connected in series to the terminal line.

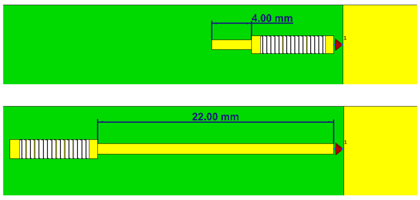


Fig. 2. Antennas with equivalent resonance frequency. Top: Base loaded monopole antenna. Bottom: Top loaded monopole antenna

III. Ground Plane Effect

In this section, several configurations have been designed with the chip antenna because depending on the orientation of the chip antenna and the terminal line, current cancellations may appear. All the solutions are tuned at 868 MHz ISM Band and will be used for the analysis of the effect of the ground plane in terms of radiation.

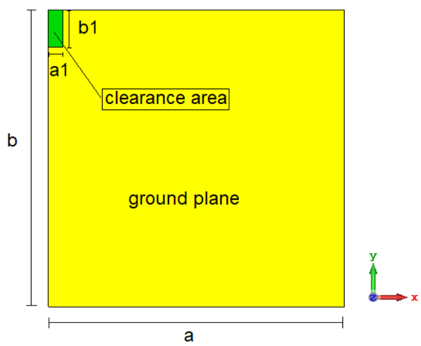


Fig. 3. PCB used for the study with a size of a×b. Material: FR4 1.6 mm, copper

The size of a ground plane has an enormous role in the radiation of a small antenna. Moreover, the position of the antenna is a critical decision which may reduce the radiation efficiency widely if placed in a wrong location. Another feature which has to be considered is the cancellation produced by the interaction of the antenna and the surrounding walls .Consequently, the clearance area must be chosen in concordance.

In this section a study of the shift of the radiation efficiency depending on the previous described factors has been realized. The scenario chosen for the study is a infinitely biased squared FRT PCB with a size of a×b. The clearance area (green area in Fig. 3) where the antenna will be placed, has a dimension of a1 x b1.

A. Antenna position

The first study analyze the effect of shifting an antenna around the perimeter of the ground plane. The configuration with the chip antenna in perpendicular to the terminal line, resonating at 868 MHz, has been used.

In Fig.4 a) the effect of shifting an antenna from the top-left corner(y=0) to the center of the left side of the PCB is depicted. The size of the ground plane is 200×200 mm and the clearance area 10×200 mm (Fig. 3). Several position have been analyzed, moving down the antenna a distance from y=0 mm to y=100 mm.

Fig. 4 b) shows the radiation efficiency obtained for each position. The results show a reduction of efficiency with the variable y, with a minimum obtained when the antenna is at the center of the clearance area (y=100 mm). The first conclusion obtained is that placing an antenna at the corner of a squared PCB has higher radiating performance than placing it in the middle of the external sides.

An analysis of the currents in the structure (Fig. 4 c)) shows that when the antenna is at the corner the current flows diagonally until the opposite corner, and when the antenna is placed at the center of a external side, the current flows from the left to the right side, having a smaller path than the previous configuration.

B. Ground Plane reduction

The second analysis is based on the effect of reducing the size of the ground plane in terms of radiation efficiency. For this study, the same antenna configuration is used as in section II.A. The antenna is fixed on the top-left corner, and the clearance area is fixed to 10λb mm. The dimension of the squared PCB has been reduced from a=b=200 mm to a=b=50 mm (Fig. 5 a)).

Fig. 5 b) shows a reduction of radiation efficiency for smaller ground planes. From a=b=100 mm, the efficiency begins to saturate and the increase is not significant with the size. The loss of radiation efficiency between 100 mm^2 PCB and 50mm^2 PCB is 3dB. In terms of input impedance, the value of the Re(Z_{11}) increases with the size of the ground plane Fig. 5 c). For very small ground planes, a matching circuit must be added in order to rise the Re(Z_{11}).

As a general recommendation, in a squared PCB with antenna at the corner, a PCB with a size greater than $\lambda/4 \times \lambda/4$ must be used in order not to limit the radiation efficiency.

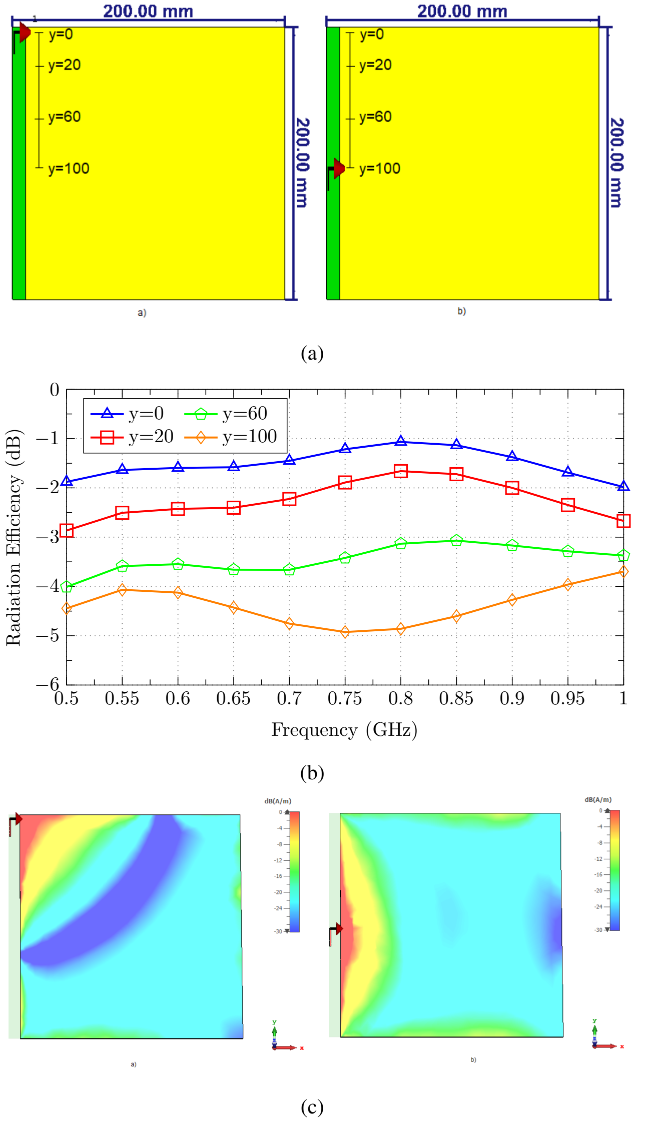


Fig. 4. a)Antenna in position y=0 mm and y=100 mm. b) Radiation Efficiency as a function of the position of the antenna. c) Current distribution for the antenna placed at y=0 mm and y=100 mm.

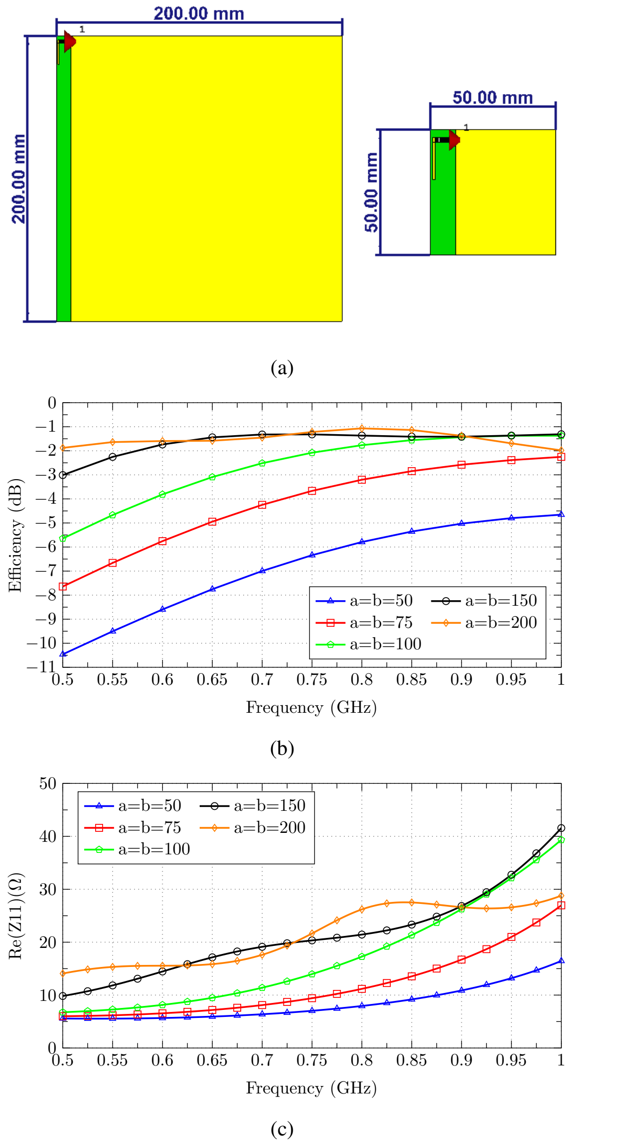


Fig. 5. a) PCB with a size of a=b=200 and a=b=50. b) Radiation Efficiency depending on the size of the PCB c) Re(Z11) of the antenna depending on the size of the PCB

C. Clearance area reduction

The third analysis is based on the clearance area where the antenna is installed. This area must not be considered only as a place where the antenna fits, but also an area in which the distance between the antenna and the ground plane must be respected. If the minimum distance is not respected the performance of the antenna may decrease due to the cancellations produced by the currents flowing in the surrounding ground plane.

Five different configurations have been studied(see Fig. 6) all of them resonating at 868 MHz. Configuration 1 and 2 connects the antenna to the terminal line perpendicularly, with the difference of in config. 1 the terminal line is the closest element to the a1 wall(see Fig. 6), and in config. 2 the closest element is the antenna.

Configuration 3 and 4 are a more compact solution with the terminal line in L shape and the last configuration (config. 5) represents an ideal disposition with the antenna and the terminal line connected in the same direction.

Unfortunately, configuration 5 is not common due to the clearance needed but it is the proper configuration to check the cancellation between the antenna+terminal line with the parallel bottom ground plane wall a1 (see Fig. 6). For this study, the antenna is in a fixed position and the clearance area (a1×b1) has been reduced from 25×200 mm to 25x20 mm. The worst scenario is represented when the parallel wall is at a distance of d1=1mm away from the antenna when the clearance is 25x20 mm. Fig. 7 represents the increase of radiation efficiency with the separation of the parallel wall (d1).

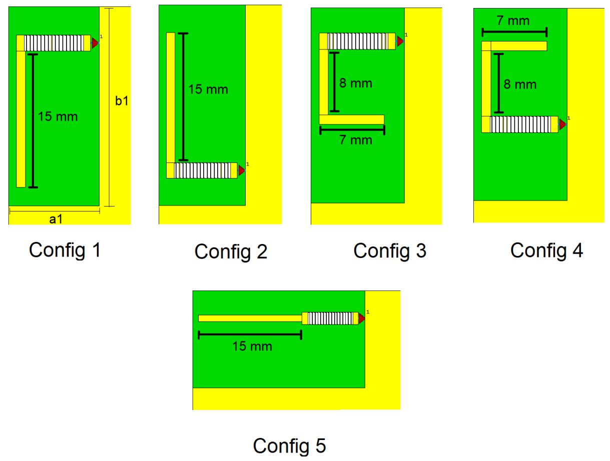
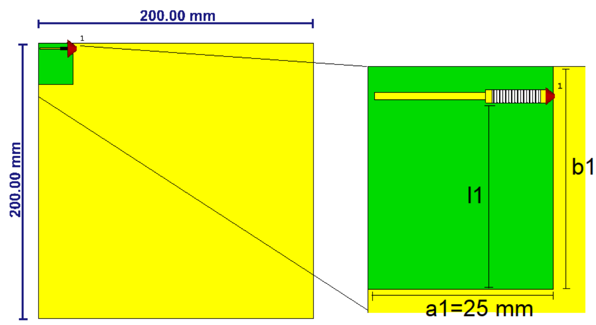
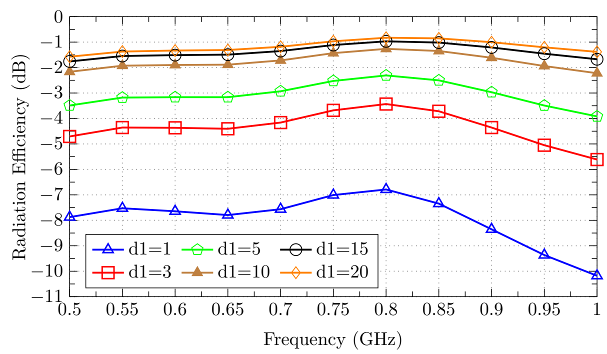


Fig. 6. Configurations used for the study of the clearance

The analysis shows a reduction of radiation efficiency with the approach of the wall, specially when the ground plane is closer than 25 mm. Due to this factor is recommended to respect this distance for a proper performance of the antenna.



(a)

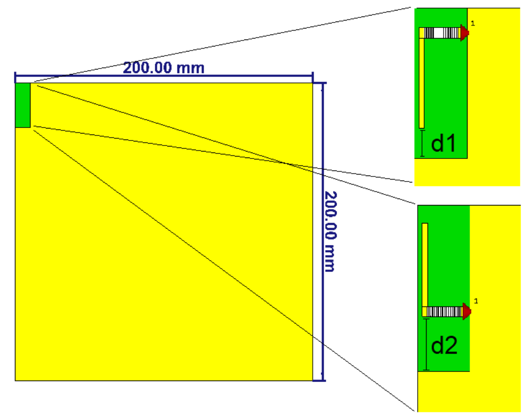


(b)

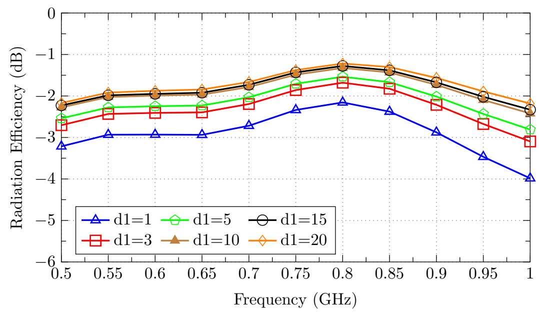
Fig. 7. a) PCB with the antenna config 5 used for the reduction of the clearance area. b) Radiation efficiency depending on the distance between the antenna and the ground plane wall a1

Config. 1 and config. 2 are based on a more realistic configuration with the antenna perpendicular to the terminal line. Two configurations has been designed in order to check if it is better to place the chip antenna or the terminal line close to the bottom ground plane wall (a1). As in the previous study, a parametric analysis has been made increasing the distance between the antenna and the wall (a1).

In Fig. 8 b) the configuration with the antenna close to the bottom part, shows a worse radiation efficiency than the configuration with the antenna in the top part. Hence, for this configuration is recommended to place the chip antenna far away from the parallel wall like in config. 1.



(a)



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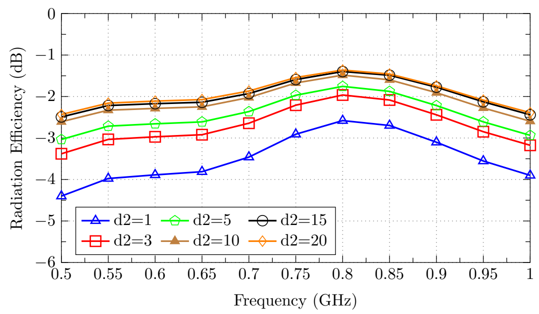
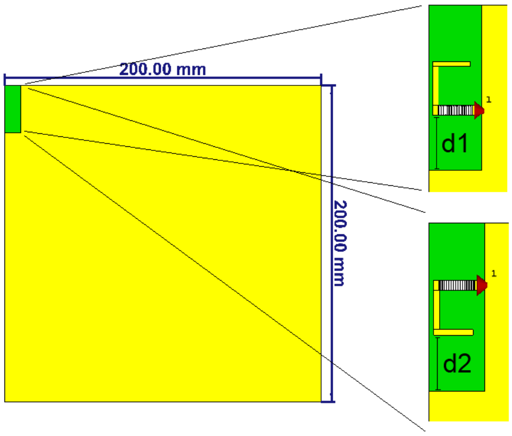


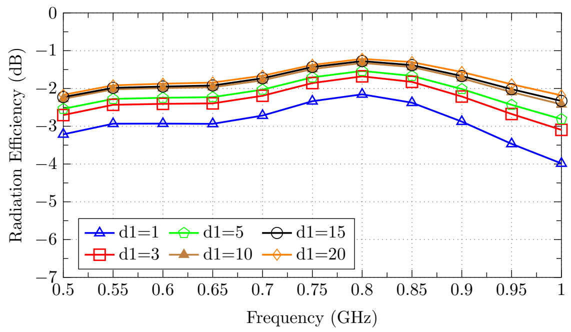
(c)

Fig. 8. a) PCB with the antenna config. 1 and 2 used for the study of the reduction of the clearance area. b) Radiation efficiency depending on the distance d1 between the antenna with config. 1 and the ground plane wall a1. c) Radiation efficiency depending on the distance d2 between the antenna with config. 2 and the ground plane wall a1

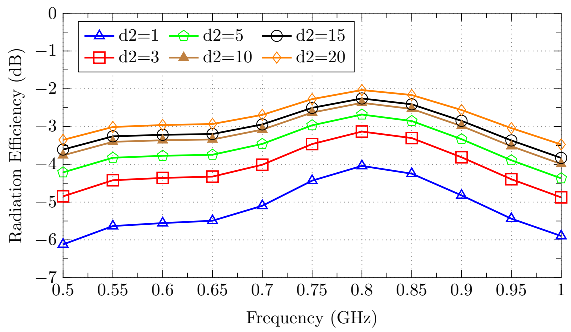
Config. 3 and config. 4 represent a configuration with a bent L terminal line. It is a realistic solution in a scenario where the clearance area is very limited. In this case, the terminal line is in parallel with the ground plane wall(a1), hence the current cancellation may increase. In order to check which configuration, 4 or 5, is more robust to current cancellation, the clearance area has been increased a distance d1 and d2(Fig. 9 a)).



(a)



(b)



(c)

Fig. 9. a) PCB with the antenna config. 3 and 4 used for the study of the reduction of the clearance area. b) Radiation efficiency depending on the distance d1 between the antenna with config. 3 and the ground plane wall a1. c) Radiation efficiency for several distances d2 between the antenna with config. 4 and the ground plane wall a1

The results in Fig. 9 b) and c) show that when the ground plane is really close, the placement of the terminal line on the bottom (config. 3) obtains worse results than config. 4. In conclusion, when the clearance area is really limited, and a L terminal line must be included, it's better to place the antenna qw in config. 4 with the antenna on the bottom part. If the distance to the ground plane from the antenna or terminal line is greater than 10 mm there's no difference between both solution, but in that case is advisable to switch to a configuration like config. 1 or 2.

IV. Conclusion

A study of the effect of a ground plane in a chip antenna has been made obtaining useful information to take into account for the implementation of a small antenna in a squared PCB. The radiation of a small antenna is limited due to its size, then the design of the ground plane connected to the antenna is critical because the main contribution to the radiation is produced by the ground plane.

There are several points which have to be respected in order to have a good radiation performance. The optimum location for a chip antenna in a squared PCB is the corners. The size of the ground plane is recommended to be greater than lambda/4 x lambda/4. A minimum distance of 10 mm must be left between the surrounding walls and all the radiation elements.

Several configurations have been analyzed and depending on the size of the clearance area a different configuration must be chosen according to the info gathered in this paper.

Acknowledgment

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