Effects of the Indoor Installation Scenario on the Radiation Pattern of Microstrip Base Station Antennas

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Abstract— **The goal of this paper is to analyze indoor installation scenario effects on mobile communication base station and WLAN access point antenna performance.**

WIPL-D, a method of moments solution based software tool, is used to develop a numerical model of microstrip patch antennas installed in complex configurations. Four typical indoor scenarios composed of dielectric and metallic walls are analyzed. Three of these scenarios have been fabricated and tested. The good agreement obtained between numerical simulations and experimental results has validated the modeling procedure.

Although this model has been developed for UMTS antennas (2 GHz), the conclusions can be extrapolated to other mobile communications and WLAN standards, such as GSM900, GSM1800, WiFi and WiMAX.

Keywords- printed antennas, BS and AP antennas, UMTS antennas, antenna installation scenarios, WIPL-D software

1. Introduction

With the explosive increase of the number of users, improving the capacity of wireless communication systems (mobile communication and WLAN) turns out to be a priority. In city centers, the reduction of the cell size to a few hundred meters leads to an increase deployment of base station (BS) and access point (AP) antenna systems. Moreover, the number of BS and AP antennas increases also due to the appearance of several operators in the same service area.

In modern wireless communication systems, a detailed propagation planning is necessary to ensure good quality of service, which means not only good coverage but also low interference. Therefore, mobile operators need to use planning tools based on accurate models where the antenna and the installation scenario are modeled as a whole. In fact, the installation environment, in particular the presence of walls, ceiling, barriers and other objects, do affect the antenna performance, mainly the radiation pattern.

Several approaches can be taken to estimate the electromagnetic field (EMF) of a BS installation [1]. However, due to the complexity of the scenarios numerical methods must be used [1]. In this paper WIPL-D [2], a Method of Moments (MoM) [3] based software tool, is used to model microstrip patch antennas installed in typical BS and AP indoor scenarios. A detailed description of the analysis and results contained in this paper can be found in [4].

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2. Numerical Model

For a proper evaluation of the EMFs of an antenna installed in a realistic environment, the first step is modeling the geometry of the problem. So both the antenna and the environment, where it is installed, need to be geometrically described, by means of their physical and electric characteristics. This first step can be harder than expected, as manufacturers usually do not give information of the exact geometry and characteristics of the antennas.

WIPL-D [2] is an efficient software tool to model 3D structures with metallic and dielectric materials and antennas. The structure under analysis is characterized by equivalent surface electric currents over metallic and dielectric surfaces. A Galerkin MoM technique is used to solve numerically an electric field integral equation and obtain the distribution of currents and charges [3]. Input impedance and radiation pattern related parameters can then be calculated.

The microstrip patch antenna finite ground plane size effects have been analyzed. The substrate has the same size of the ground plane. The square patch size (L) and feeding point have been optimized to provide 50 Ohm input impedance at 2 GHz. The input reflection coefficient (S_{11}) does not change significantly for ground planes with size (Lgp) 50% above the patch size (Lgp>1.5L).

Fig. 1 and Fig. 2 show the radiation pattern of a square patch, at 2 GHz, for different ground plane sizes. As expected, the radiation in the backside of the ground plane increases as the ground plane size decreases. In the limit Lgp=L, the front and the back radiation of the antenna cannot be distinguished. Similar conclusions about the ground plane size effects have been obtained in [5].

In the simulations of the next sections a ground plane with twice the size of the patch is used (Lgp=2L).

3. Typical Indoor Scenarios

The effects of four different scenarios, composed of dielectric and metallic elements with different dimensions, on the antenna input impedance and radiation pattern, are analyzed. These scenarios have been chosen to represent typical indoor antenna installations.

Fig. 3 presents the chosen scenarios: dielectric corner (Scenario 1); dielectric corner and ceiling (Scenario 2); dielectric corner with metallic ceiling (Scenario 3); and metallic corner and ceiling (Scenario 4). Metallic structures are modeled as brass, with an electric conductivity (σ) 26 MS/m, while ε_r is varied to study its influence on the antenna performance.

The main problem when modeling the antenna and the environment is that the structure can be large (in wavelength) and require huge processing time and memory.

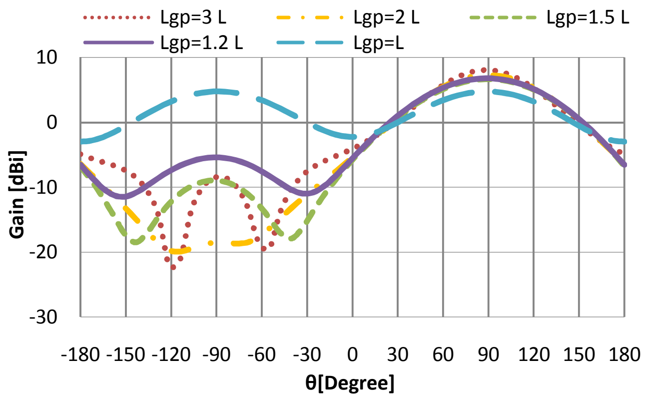

Fig. 1. E-plane radiation pattern of an isolated patch antenna.

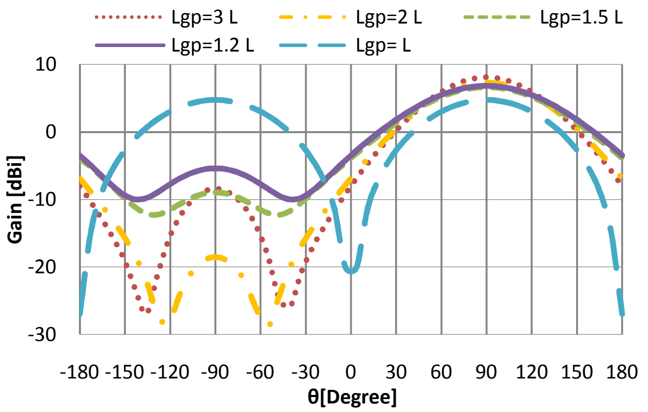

Fig. 2. H-plane radiation pattern of an isolated patch antenna.

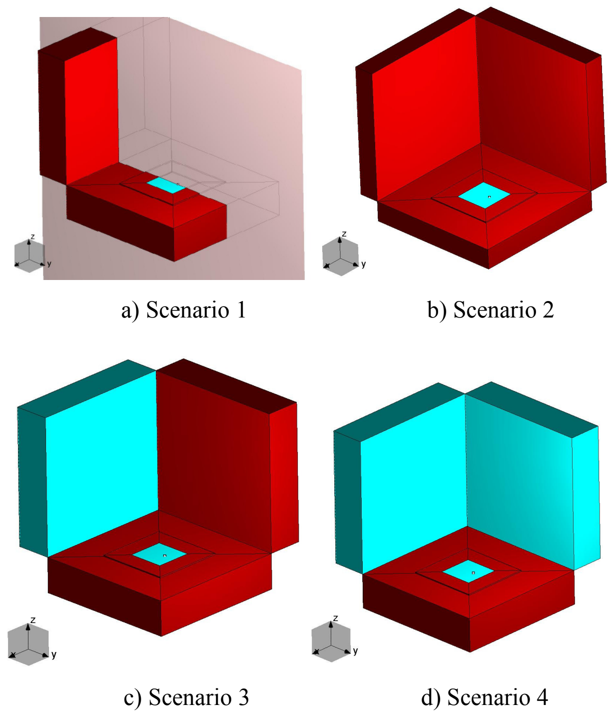

Fig. 3. Indoor simulation scenarios.

Through this study particular issues that influence the overall performance of the antenna are studied, such as the presence of different surrounding materials (metal or dielectric), and their geometrical and electric properties. For that purpose both thickness and ε_r of the dielectric materials take different values in an adequate range.

3.1. Scenarios with Dielectrics

Scenarios 1 and 2 have only dielectric walls. They correspond to typical indoor scenarios where a BS or AP antenna is installed on a dielectric wall near a dielectric ceiling or corner.

Observing the curves of the E-plane (YoZ plane) radiation pattern obtained for Scenario 1, shown in Fig. 4, it is obvious the strong influence that the dielectric corner has on the radiation pattern. With an increase of the thickness or ε_r, the nulls and lobes are more pronounced.

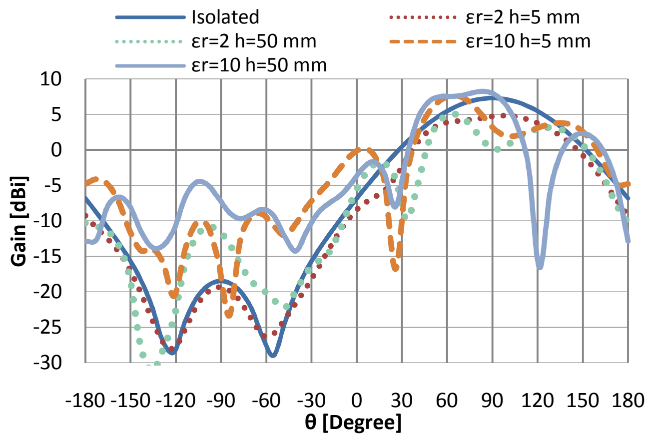

Fig. 4. E-plane radiation pattern for Scenario 1.

The E-plane, Scenario 2, where there are three dielectric panels, behaves similarly to Scenario 1, however the oscillations are smaller. As shown in Fig. 5, the H-plane (XoZ plane) radiation pattern is strongly affected by the extra wall installed.

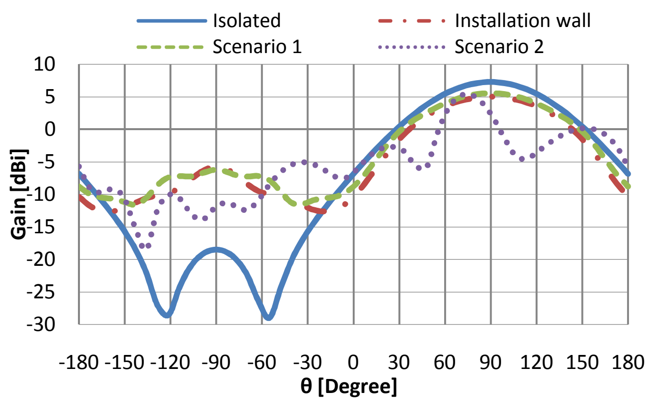

Fig. 5. H-plane radiation pattern for Scenarios 1 and 2, with walls 50 mm thick and ε_r=5.

This effect is even stronger for ticker and higher ε_r walls. It is also verified that for thicker walls there is an increase of the gain, for negative θ (back side of the antenna). It is worth to mention the great similarity between the charts of Scenario 1 and the case where there is only the installation wall.

3.2. Scenarios with Dielectrics and Metals

Scenarios 3 and 4 correspond to an antenna installed on a dielectric wall near a corner with a metallic ceiling and a dielectric wall or metallic wall, respectively. Analyzing the simulation results obtained for Scenario 3 and Scenario 4, the important conclusion that can be taken is the similarity of the E-plane radiation patterns (Fig. 6). This happens because Scenario 4 can be obtained from Scenario 3 by the substitution of the dielectric wall installed parallel to the YoZ plane, with a metallic one. The same similarity is also verified when the thickness and ε_r of the dielectric walls are changed.

When the wall thickness is 50 mm, the charts of the two scenarios are very similar. There is only an increase of the “nulls” and “lobes” on Scenario 4.

It is also worth noting the large number of “lobes” and “nulls”, originating for some angles a gain higher than when the antenna is alone. This phenomenon is due to the reflection of waves in the metal wall that can have positive or negative contributions to the gain of the antenna, creating "lobes" or "nulls", respectively.

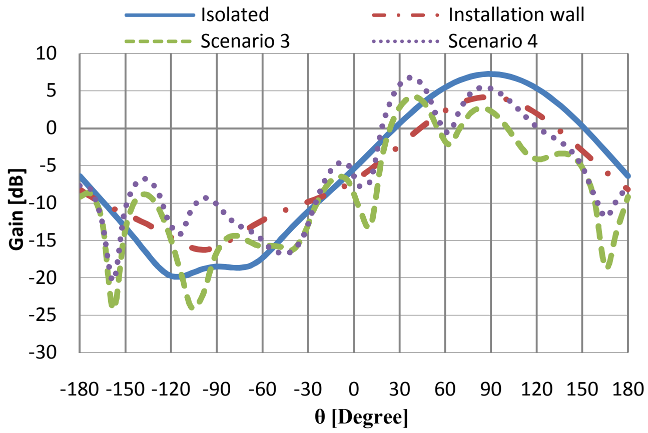

Fig. 6. E-plane radiation pattern for Scenarios 3 and 4, with walls 5 mm thick and $\varepsilon_r = 5$.

Analyzing now the charts for the H-plane, shown in Fig. 7, it can be observed that the similarities between the two scenarios, that previously were verified, are not present any more. Such happens due to the fact that in Scenario 3 the wall parallel to the YoZ plane is dielectric, whereas in Scenario 4 it is metallic.

Moreover Scenario 3 is more sensitive to variations of the thickness and ε_r. Scenario 4, has the only dielectric wall where the antenna is installed, is more sensitive to changes for θ negative.

4. Experimental Validation

To validate the WIPL-D numerical simulation results the isolated antenna and three of the scenarios simulated (Scenario 2, Scenario 3 and Scenario 4) have been fabricated and measured. The radiation pattern of the 4 antenna prototypes have been measured in an anechoic chamber (Fig. 8).

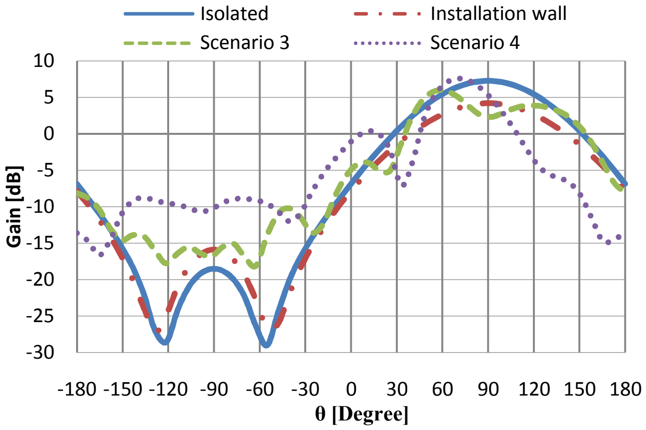

Fig. 7. H-plane radiation pattern for Scenarios 3 and 4, with walls 5 mm thick and $\varepsilon_r = 5$.

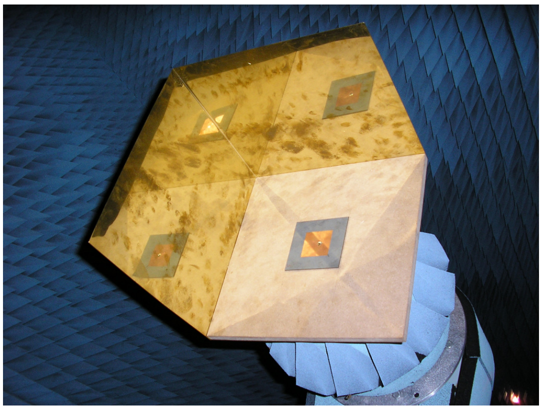

Fig. 8. Prototype of Scenario 4 in the anechoic chamber.

The dielectric walls have been made of medium density fiberboard (MDF) wood panels (ε_r=2.17, tanδ=0.17) [4]. The metallic walls have been implemented in brass. A photolithography technique has been used to print the antennas on a 62 mils thick Duroid 5880 substrate (ε_r=2.2).

In all radiation pattern charts there is an exclusion zone (shadowed in blue) caused by the positioner where the antenna is mounted. As the positioner is 34 cm away from the antenna and has a diameter of 38 cm, there is a range of about 60º that is blocked by it.

Simulation and experimental E-plane and H-plane radiation patterns of Scenario 2 are compared in Fig. 9 and Fig. 10, respectively. A good agreement is obtained. There are some fluctuations in the E-plane experimental results probably due to reflections that may have occurred in the antenna fixture holder. For the H-plane the most visible differences are “nulls” with a better definition in the simulated results. Also for |θ|>120º the measured gain is considerably less than the simulated one.

For Scenario 4 a good agreement between the measured and simulated results can be observed in Fig. 11 and Fig. 12, representing the E-plane and H-plane radiation patterns, respectively. For the E-plane (Fig. 11) the two curves are almost identical. For the H-plane there is also a very good agreement between the two curves, being the most significant variation the difference of gain in the “nulls” created at θ = 90º, and θ = -60º.

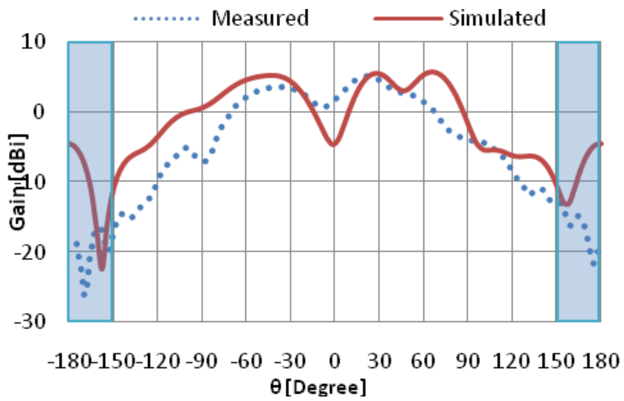

Fig. 9. E-plane radiation pattern of Scenario 2.

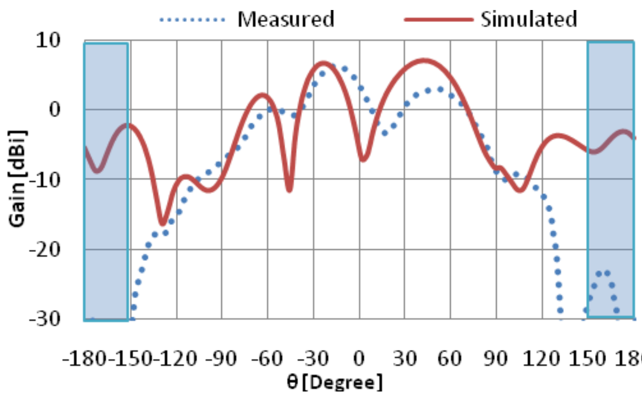

Fig. 10. H-plane radiation pattern of Scenario 2.

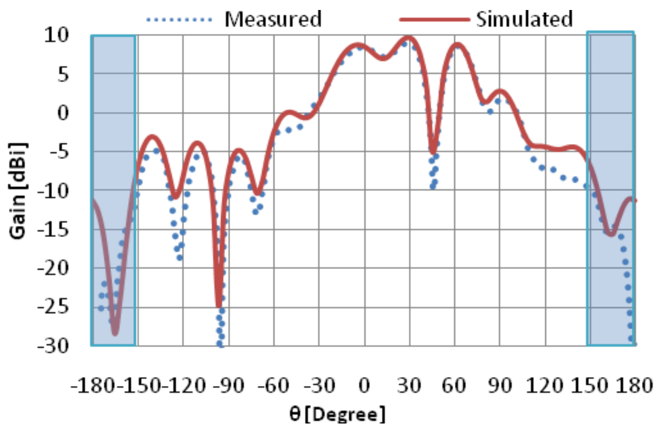

Fig. 11. E-plane radiation pattern for Scenario 4.

The good agreement obtained between WIPL-D numerical simulations and experimental results has validated the modelling procedure used. Therefore, it can be concluded that the adopted geometrical models are a good approach to analyze real scenarios. Although with reduced geometrical dimensions WIPL-D models still lead to accurate results and a good overall evaluation.

5. Conclusions

A procedure to model accurately microstrip patch antennas installed in complex environments has been presented. It is applied to mobile communication BS and WLAN AP antennas used mainly in indoor scenarios.

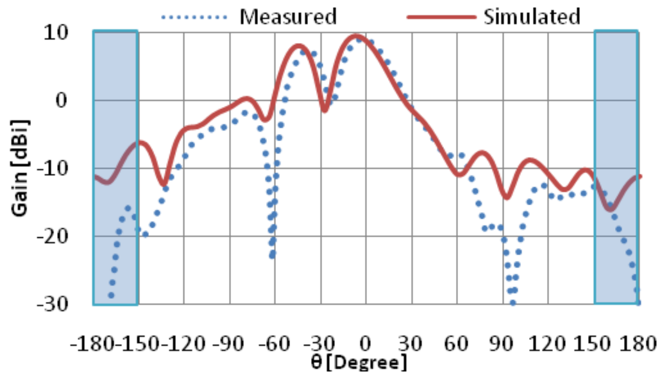

Fig. 12. H-plane radiation pattern for Scenario 4.

A study on the influence of the ground plane size has been carried out. The main conclusion is that for square antennas with square ground planes 50% bigger than the patch the ground plane size effects are not very significant.

From the analysis of the antenna radiation patterns in the various scenarios, it can be concluded that the geometry of BS installation and also the materials in the environment of the antenna may have a strong influence on the way it radiates in space, almost always leading to the deformation of the (isolated antenna) radiation pattern.

As expected, Scenario 1 presents an H-plane radiation pattern very similar to the isolated antenna one. In the E-plane, the agreement is also acceptable for thin walls, but there is a significant difference for thick walls. For Scenario 2, there is a good agreement with the radiation pattern of the isolated antenna for thin walls with small ε_r and thickness. Scenario 3 presents in the H-plane a good agreement with the isolated antenna for thin walls with small ε_r, while for the E-plane there is an increase of directivity. For Scenario 4 there is also an increase of directivity in both planes.

None of the scenarios have a significant effect on the resonant frequency and input impedance of the antenna.

Prototypes of an isolated antenna and of antennas installed in 3 scenarios have been fabricated and measured in an anechoic chamber. The good agreement obtained between the simulation and experimental results has validated the modeling procedure.

Although the work has been developed for UMTS (2 GHz), the main conclusions are valid for other wireless technologies, such as GSM, WiFi, and WiMAX. In these frequency bands (900 MHz, 1800 MHz, 2.5 GHz, and 5 GHz) no significant differences in the EMFs behavior are expected to occur.

The main conclusion of this paper is that microstrip patch antennas, used in indoor BSs and APs, and the scenario where they are installed need to be modeled as a whole.

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