Study and Design of Reduced Thickness Antennas for Mobile Devices

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Abstract—Considering the increasing evolution of wireless communications and the reduction of device thickness, low profile antennas for mobile networks have increasingly taken a leading role in increasing the capacity and speed of data transmission. Several types of networks have emerged, particularly WLAN networks based on the IEEE 802.11 protocol, which through MIMO solutions are capable of accomplish the requirements and improve signal quality.

This paper presents an antenna with operation in ISM bands of 2.45 GHz and 5.8 GHz for applications in wireless networks. The geometry of the solution is composed of planar-like structures printed on both sides of the substrate Rogers® 3035 substrate with interdigital capacities. The integration of the antenna into a MIMO solution is also addressed in this study.

The parameters of electromagnetic behavior such as the return loss, radiation patterns and radiation and total efficiencies, as well as the evaluation parameters of MIMO solutions (correlation coefficient and diversity gain) were evaluated in free space.

The MIMO antenna, after optimization, was fabricated and its performance was analyzed by means of measurements of the return loss in the laboratory. The results obtained were satisfactory, however, there was a mutual coupling in the lower band.

Nevertheless, there was substantial improvement in overall efficiency as intended.

Index Terms—Low profile antennas; WLAN (Wireless Local Area Network); ISM (Industrial, Scientific and Medical) bands of 2.45 GHz and 5.8 GHz; return loss, MIMO.

I. INTRODUCTION

With technological progress, the smaller size and thickness of mobile devices has increased the challenge in antenna design. These are increasingly confined to a smaller space since components such as the battery and processing unit have a fixed size. The wireless devices thus increasingly require the existence of low-profile antennas, of reduced dimensions and with multiple bands, and can be integrated into several antennas systems, particularly in MIMO structures [1].

Applications for wireless networks have begun to become more and more important due to the decrease in the existence of cables and the need for a greater number of connected elements. Several applications have emerged by integrating these low-profile antennas into multiple sectors such as the military, industry and domestic use [5].

After some research in the available networks, WLAN was the chosen one because of the large applications and easy implementation and therefore the antenna performance is tested in ISM bands of 2.45 GHz and 5.8 GHz.

After a brief introduction, the second section describes the proposed antenna, the following section studies the application of this antenna in MIMO systems and finally some conclusions are described.

II. ANTENNA DESIGN AND PERFORMANCE

Considering the antennas suggested in [2] [3], it is proposed in this dissertation a double-sided printed antenna with a dimension of 50 mm × 56 mm in a RO3035® substrate. Its geometry is composed of a horizontal planar structure (with respect to that represented in Figure 1) with a printed interdigital capacity and by a vertical line of width 1.73 mm so as to be adapted to 50 Ω. The opposite face is also composed of a horizontal structure together with the ground plane interconnected by a connecting element. On this face, the horizontal element size is half the effective wavelength for the lowest resonant frequency and is therefore responsible for the resonance in the ISM band of 2.45 GHz. After the optimization process using the CST simulation software Microwave Studio™, the proposed solution is represented in the Figure 1. The antenna was simulated in free space using a coaxial cable of 2.5 cm.

![Fig. 1. Proposed antenna: (a) front plane, (b) ground plane and dimensions (mm).](image-url)

The printed interdigital capacity plays a key role in the antenna operation in the bands for WLAN networks. The main reason for its introduction is the reduction of the influence of the resonance in the frontal plane (responsible for the band of 2.45 GHz) and maintenance of the functionality of the resonance in the ground plane (band of 5.8 GHz). Thus it functions as a high pass filter where the 2.45 GHz frequency...
is cut off and the 5.8 GHz frequency belongs to the filter bandpass [3]. It allows the generation of a second resonance frequency, since, according to the theory of transmission lines, when the line length, \( L \) obeys the inequality 1.

\[
\frac{\lambda}{4} < L < \frac{\lambda}{2}
\]

Where \( \lambda \) is the effective wavelength, an open circuit occurs allowing the existence of the resonant frequency. The Return Loss, \( |S_{11}| \), is the parameter that relates the incident and reflected power of the antenna, due to its own mismatching, and it is expressed by the equation 2, in [4].

\[
|S_{11}|_{dB} = 10 \log_{10} \frac{P_R}{P_I}
\]

It is considered that an antenna is tuned in a frequency band when the reflected power is less than or equal to 10% of the incident power, \( P_R \leq 0.1 \times P_I \). This means \( |S_{11}| \leq -10dB \). Another criterion, less demanding, often used in mobile terminals, corresponds to a ratio between reflected power and incident power less than or equal to 25%, i.e., \( P_R \leq 0.25 \times P_I \), or, \( |S_{11}| \leq -6dB \) [10]. Figure 2 shows that this antenna is tuned in ISM bands 2.45 GH and 5.8 GHz.

The optimization of the antenna was performed in evaluate the sensitivity of the antenna return loss, \( |S_{11}| \), to variations of the most relevant design parameters. \( |S_{11}| \) was simulated for different substrate’s dielectric permittivity, thickness and width, position of the coaxial cable, dimensions of the planar rectangular structures and dimensions of the interdigital capacity. 3 shows the surface current distribution at both frequencies, 2.45 GH and 5.8 GH. This shows a clue to the importance of the geometrical parameters dimensions on the antenna performance. The study showed that one of the most influential structures in \( |S_{11}| \) behavior is the interdigital capacity and his dimensions.

The radiation and total efficiencies are also studied, through simulations and measurements. According to IEEE Standard Terms and Definitions for Antennas [5] the antenna radiation efficiency is defined as “the ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter”. The total antenna efficiency accounts for both dissipation and mismatch losses [6]. Table 1 exhibits both efficiency simulation results at 2.45 GHz and 5.8 GHz.

![Fig. 2. Simulation result of the antenna \( |S_{11}| \).](image)

![Fig. 3. Surface current distribution: (a) at 2.45 GHz and (b) at 5.8 GHz.](image)

![Fig. 4. Simulation result of the antenna \( |S_e| \).](image)

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Radiation Efficiency [%]</th>
<th>Total Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.45 GHz</td>
<td>( \geq 95 )</td>
<td>( \approx 94 )</td>
</tr>
<tr>
<td>5.8 GHz</td>
<td>( \geq 81 )</td>
<td>( \approx 92 )</td>
</tr>
</tbody>
</table>

TABLE I

It is possible to observe the reduced value of the total efficiency in 5.8 GHz band. So, in order to maximize this value, MIMO solutions are evaluated.

### III. Antenna MIMO Design and Performance

In order to improve some parameters, namely efficiency, the integration of the simulated antenna in a solution with spatial diversity was studied. These systems with diversity are mainly evaluated through correlation coefficient, diversity gain and antenna efficiency. In this way, the configuration shown in Figure 4 is proposed, where two antennas with equal geometry and symmetric arrangement are printed on the substrate and fed by two ports. In figure 4c the optimized dimensions of the interdigital capacity are detailed taking into account the desired operating bands.

In Figure 5 we present the curves referring to the simulation of the reflection coefficients of the MIMO solution. It is possible to verify that there are two resonances in the bands required for WLANs, 2.45 GHz and 5.8 GHz. Both fulfill the criterion that establishes the proper functioning of the antennas since they have values below -10 dB. Only two curves can be visualized since the rest are overlapping due to the symmetry of the solution since \( |S_{11}|=|S_{22}| \) and \( |S_{12}|=|S_{21}| \).

There is mutual coupling due to the small spacing between the position of the antennas, thus there is little isolation between the ports in the lower band.

Based on Fig. 5 it is possible to characterize an operating frequency band in percentage bandwidth, \( BW_{\%} \). The expression of the bandwidth is given by equation 3 according to [11], is

\[
BW_{\%} = 200 \times \frac{f_{\text{max}} - f_{\text{min}}}{f_{\text{max}} + f_{\text{min}}}
\]

\( f_{\text{max}} \) and \( f_{\text{min}} \) being the maximum and minimum frequencies of the operating band, respectively.
This is a function of the maximum and minimum values of the operating band of the antenna, $f_{\text{min}}$ and $f_{\text{max}}$. Therefore, the antenna on Fig. 4 is tuned in the required bands, as the $|S_{11}|$ is lower than -10dB at those frequencies. Considering that criterion ($|S_{11}| \leq -10\text{dB}$), at the simulated frequencies, in free space, the percentage bandwidth is shown in Table II. The MIMO antenna is tunned from 2.40 GHz to 2.53 GHz, with a 5.4% of bandwidth, and from 5.75 GHz to 5.84 GHz with a 1.40% of bandwidth.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Radiation Efficiency [%]</th>
<th>Total Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.45 GHz</td>
<td>$\approx 94$</td>
<td>$\approx 78$</td>
</tr>
<tr>
<td>5.8 GHz</td>
<td>$\approx 82$</td>
<td>$\approx 79$</td>
</tr>
</tbody>
</table>

**TABLE III**
EFFICIENCY SIMULATIONS OF THE MIMO ANTENNA.

Figure 6 show the bi-dimensional radiation patterns in the $xz$, $yz$ and $xy$ planes. The $xy$ and $yz$ planes can be named as vertical planes and the $xz$ as the horizontal plane. The radiation patterns (gain) given below, correspond to both 2.45 and 5.8 GHz bands, respectively.

It is concluded that the antenna at 2.45 GHz radiates almost omnidirectionally in $xz$ plane and presents mostly two main lobes in the other planes. Furthermore, at 5.8 GHz the antenna presents a similar radiation pattern at $xz$ plane and in the other planes multi-lobes configuration.

The radiation and total efficiencies are also studied, through simulations. TableIII exhibits efficiency simulation results at 2.45 GHz and 5.8 GHz.
As for the performance, present in Figure 9 it is possible to establish a good agreement in the 2.45 GHz band as the reflection coefficients are in the range of -21 dB, fulfilling the criterion established ($|S_{11}| \leq -10\, \text{dB}$). The second band has shifted to slightly higher frequencies, with resonance at 5.95 GHz. By still fulfilling the criterion considered once the reflection coefficient has a value of -15 dB.

IV. CONCLUSIONS

This paper presents the design and performance of dual-band MIMO solution on a Rogers 3035 substrate. The proposed antenna is double-faced and S-Parameters has been simulated and measured. The results exhibit good agreement in free space.

Efficiency was improved and the great importance of the interdigital capacity in the second resonance location was observed. Before the manufacturing process all dimensions were tested to the optimum value. A mutual coupling between the ports in the 2.45 GHz band (about -7 dB) has been found but comply with the criterion which establishes operation when the reflection coefficient is less than -6 dB. The proposed MIMO antenna is a good candidate for ISM dual-band 2.45 GHz and 5.9 GHz WLAN applications.

REFERENCES