Improving Isolation in MIMO Antenna for WLAN Applications

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Abstract: - The system Wireless Local Area Network (WLAN) presents minimum bandwidths to provide required transmission data rates, isolation can also be improved using multiple input multiple output (MIMO) scheme increasing their capacity. In this paper, the Decoupling Networks technique is presented to reduce the coupling between the elements of the MIMO antenna and thus improve data rate with a 2x2 MIMO antenna system. The dielectric used was FR4 substrate with dielectric constant $\varepsilon_r = 4.4$ and thickness of substrate 1.544 mm. The S_{11} and S_{12} scattering parameters were obtained as well as ECC at the resonance frequency and bandwidth. The radiation pattern and the current density are simulated by HFSS. The antenna size is 80 x 65 mm^2.

Key-Words: - MIMO antenna, WLAN, ECC, antenna bandwidth, antenna pattern, Decoupling Network.

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1 Introduction

Nowadays, in jobs, offices, schools, government agencies, hospitals, industry, cultural centers, and transportation systems, among others, there are thousands of instrumentation systems, monitoring systems, control systems, and visualization systems. etc., operational around the world, that present wireless communication stages with WLAN 802.11, 802.11b, and 802.11g requirements. These systems work within the Industrial, Scientific, and Medical (ISM) license-free band (from 2.4 GHz to 2.4835 GHz.).

The 802.11 standard initially established transmissions of up to 2 Mbps in the 2.4 GHz band using quadrature phase-shift keying (QPSK) modulation and frequency hopping spread spectrum (HFSS), [1]. WLAN systems have several advantages, [2]:

- Low complexity.
- Mobility.
- Low cost.
- High degree of scalability.

The WLAN system with 802.11, 802.11b, and 802.11g standards achieve data rates of up to 2 Mbps, 11 Mbps, and 54 Mbps respectively, showing minimum bandwidths of 20 MHz, [3].

Dual-band systems that work in the 2.4 GHz and 5 GHz bands (802.11ax and 802.11n) maintain communication with devices that operate in the 2.4 GHz bands but reach higher speeds using higher performance access schemes and through the use of MIMO antennas increasing transmission rates, [4].

In the aforementioned systems, there are overlaps between the various channels that comprise them, so it is necessary to increase the isolation between the elements to improve the transmission rates offered. To reduce the overlapping can be used non-consecutive channels, [5].

Patch microstrip antennas are commonly used in WLAN systems. Patch antennas offer advantages such as low complexity in their design and very low cost, [6], [7], [8], [9], [10], [11].

In MIMO antenna systems, one of the problems that arise is the high electromagnetic coupling between its radiating elements, due to the proximity between them, as well as the radiated power, [12]. For this reason, it is very important to use techniques to increase the isolation between each of the elements of the MIMO antenna, the diversity of the system increases the capacity of the network and decreases fading.

The decoupling network technique reduces the mutual coupling by providing negative coupling. This technique is simple and lumped elements can be used to reduce the size of the decoupling network. Among several techniques used to improve electromagnetic isolation, the decoupling network is one of the techniques that present the highest isolation, better than neutralization lines and parasitic element techniques, [13].

In this article, the decoupling network technique is presented to increase the isolation between two elements in a MIMO antenna for WLAN applications.

The MIMO antenna was designed over an FR4 substrate with a dielectric constant of 4.4 and a thickness of 1.544 mm.

The simulations were carried out using Ansys HFSS (High-Frequency Structure Simulator).

2 Antenna Design

The MIMO antenna is based on the rectangular patch antenna, which operates at a frequency of 2.45 GHz (Figure 1). This resonant frequency complies with the WIFI bandwidth which starts from 2.412 GHz to 2.712 GHz.

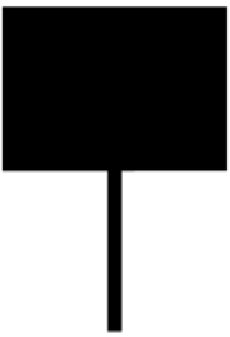

Fig. 1: Rectangular Patch Antenna

Figure 2 shows the distribution of the radiator elements of the 2x2 MIMO antenna.

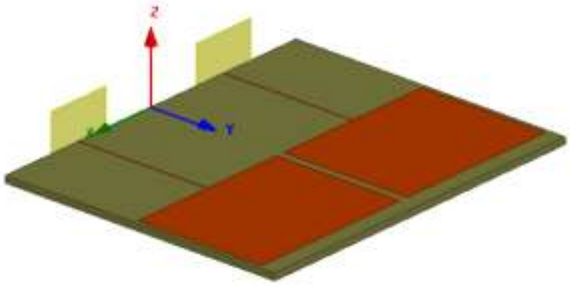

Fig. 2: MIMO Antenna

The patch antenna design is based on the transmission line model, using equations (1-4).

$$W = \frac{\upsilon_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-1/2} \quad (2)$$

$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

$$L = \frac{\lambda}{2} - 2\Delta L \quad (4)$$

Where:

W wide of the antenna [m]
ε_r dielectric constant
f_r resonant frequency
υ_0 speed of light [m/s]
ε_{reff} effective dielectric constant
h width of the substrate
L long of the antenna [m]

The antenna feeder transmission line is based on the λ/4 transformer model and also the decoupling network.

The substrate material is FR4, as well as the resonant frequency of 2.4 GHz.

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Resulting in the dimensions of the antenna and feeder, as shown in Figure 3.

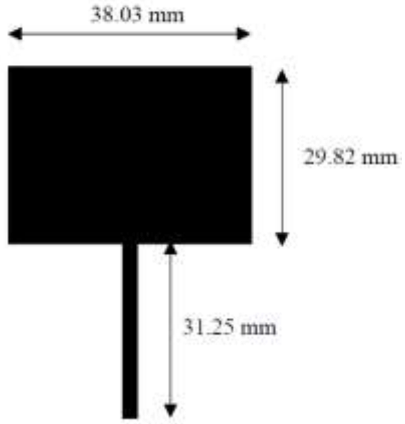

Fig. 3: Rectangular Patch Antenna with dimensions

The analysis and simulation of the MIMO antenna were performed with and without the decoupling network (Figure 4 and Figure 5). The radiator elements were brought closer to reduce the size of the antenna, so it was necessary to carry out a parametric analysis of the decoupling network structure to reduce the coupling between the antenna elements, resulting in an antenna size of 80 x 65 mm^2.

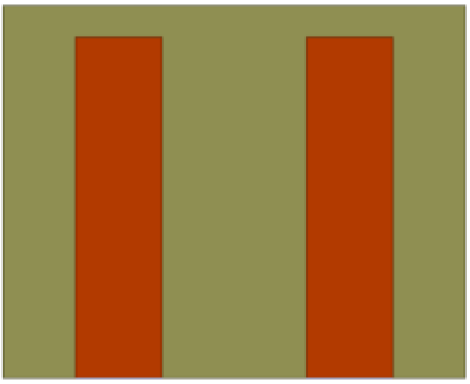

Fig. 4: Ground plane without decoupling network

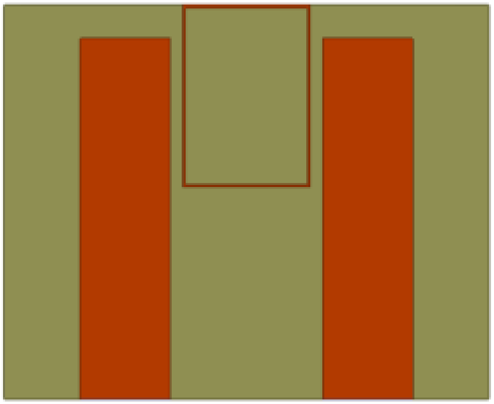

Fig. 5: Ground plane with decoupling network

3 Results

The return losses, the parameter S_{11} is shown in Figure 6, we can see that the resonant frequency is 2.4560 GHz with a bandwidth of 111.5 MHz according to the 802.11, 802.11b, and 802.11g standards. The coupling at the resonant frequency is -26.7734 dB.

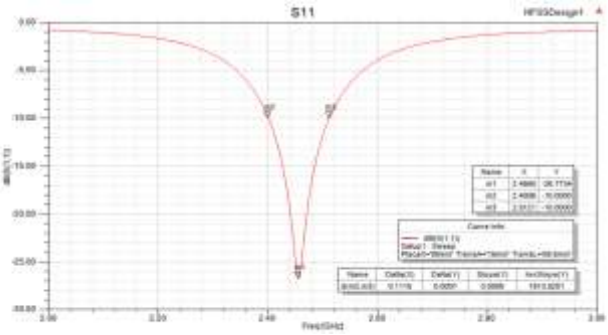

Fig. 6: S_{11} Parameter without Decoupling Network

In Figure 7, parameter S_{12} presents a maximum value of -21.7583 at a frequency of 2.4360 GHz (within the bandwidth of the MIMO antenna), where the minimum acceptable value is -15 dB of electromagnetic isolation.

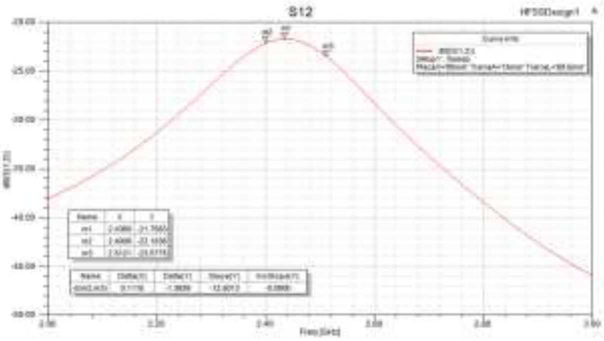

Fig. 7: S_{12} Parameter without Decoupling Network

Another parameter that shows the degree of electromagnetic isolation is the Envelope Correlation Coefficient (ECC), the value of this parameter is desirable to be less than 0.5 (ECC < 0.5), and the ECC is obtained from the scattering parameters S (equation 5), [14], [15]. The ECC obtained is 0.17, accomplishing that requirement.

$$ECC = \frac{|S_{11}{}^{*}S_{12} + S_{21}{}^{*}S_{22}|^2}{(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)} \quad (5)$$

Subsequently, the parameters S_{11} (Figure 8) and S_{12} (Figure 9) of the MIMO antenna with a decoupling network on the ground plane were obtained (Figure 5).

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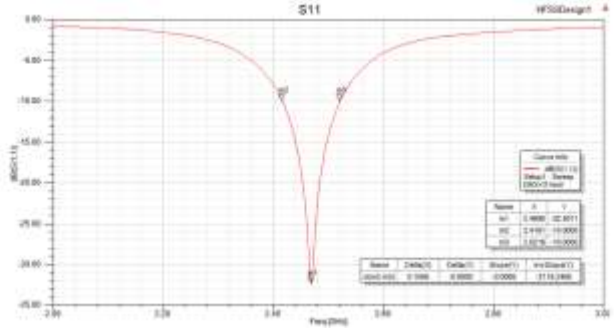

Fig. 8: S_{11} Parameter with Decoupling Network

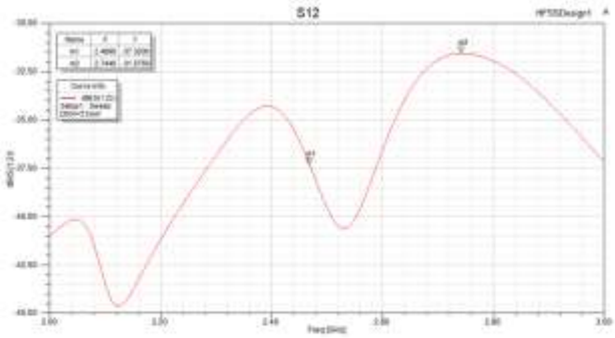

Fig. 9: S_{12} Parameter with Decoupling Network

Figure 8 shows the resonance frequency at 2.469 GHz (7 MHz offset from the original frequency), in addition, it improved its coupling by 5.6277 dB (-32.4011 dB).

The bandwidth obtained is 105.5 MHz (from 2.4161 GHz to 2.5216 GHz). However, parameter S_{12} presents less coupling, increasing its isolation by 12.5 dB (from -21.75 dB without the decoupling network to -34.25 dB with a decoupling network). The ECC was decreased to 0.1.

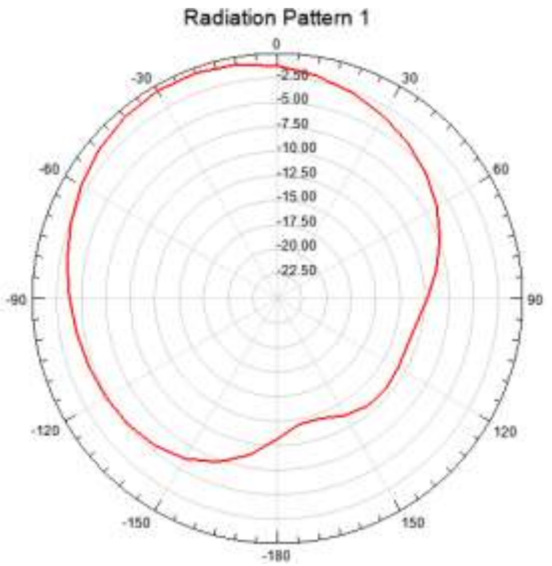

Fig. 10: Radiation Pattern of the MIMO Antenna (Front Plane)

The radiation pattern of the MIMO antenna is shown in Figures 10 and Figure 11 (Figure 10 for the frontal plane and Figure 11 for the transverse plane). Quasi-omnidirectional behavior is observed for mobile applications.

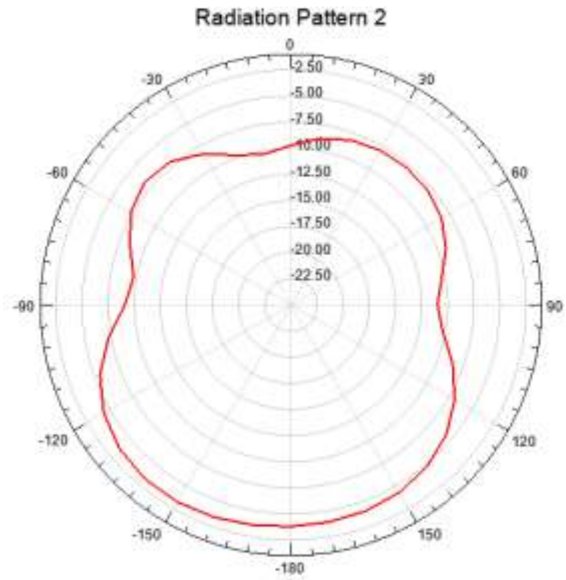

Fig. 11: Radiation Pattern of the MIMO Antenna (Lateral Plane)

The parameters obtained are summarized in Table 1.

Table 1. Performance parameter of the MIMO antenna

Low-High Cutoff Frequency (GHz)	Size (mm^2)	S_{11} (dB)	S_{12} (dB)
2.4161-2.5216	80x65	- 32.4	-34.25

The surface currents distribution was reduced in the MIMO antenna with a decoupling network (Figure 12).

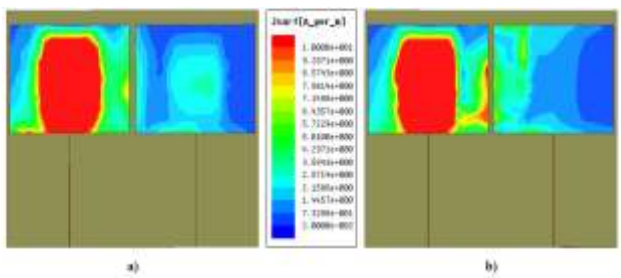

Fig. 12: Surface current distribution in MIMO antenna a) without decoupling network and b) with decoupling network

Figure 12 shows higher current densities of the antenna in the case where there is no decoupling network and in the antenna with the decoupling network the current densities are lower.

4 Conclusion

Introducing the decoupling network in the MIMO antenna for WLAN applications, presents a decrease of 5% of the bandwidth presented in the MIMO antenna without the decoupling network.

A considerable improvement in the electromagnetic isolation between the elements of the MIMO antenna was obtained by an increase of 12.5 db.

A VSWR<2 was obtained within the WLAN bandwidth presented by the two-element MIMO antenna with a reduced size of 80 x 65 mm^2. Its radiation pattern is quasi-omnidirectional, which is suitable for mobile applications.

The Decoupling Networks technique can be used with others to improve the isolation and can be implemented in broad and wide bandwidth MIMO antennas.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

-Karol Bautista carried out the antenna design and simulation of the S_{12} parameter. Also, she obtained the surface currents distribution simulation.

-Edgar Andrade did the design and parametric study of the decoupling network and revised the methodology.

-Mario Reyes did the simulation and analysis of the radiation pattern. Also the supervision and validation.

-Hilario Terres and Sandra Chávez carried out the calculation of ECC and validation of the results. Both supervised the methodology.

-José Viveros described the introduction of the paper and the design of the feeder transmission line. Also, he carried out the simulation of the S_{11} parameter.

-René Rodríguez checked spelling and grammar. Also, he wrote, review and edited. Finally, he helped with supervision

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Conflict of Interest

The authors have no conflict of interest to declare.

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