Dual Band Slotted Rectangular Microstrip Antennas in Mobile Radiocommunication Systems

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Abstract: - The goal of this paper is to propose a rectangular microstrip antenna with two frequency bands is carried out. The rectangular patch has a square slot to obtain the second band. The antenna has been designed for laboratory subjects in undergraduate courses in RF theory and applications. The antenna was modeled, simulated, and optimized using High Frequency Structure Simulation (HFSS). Additionally, this work includes the analysis of the ground layer size, which modifies the two operating frequencies and corresponding bandwidths. The H and E patterns and S_{11} parameter were obtained in the computational tool mentioned before and modified in order to get the optimal responses.

Key-Words: - Patch antenna, slotted patch antennas, multi-band microstrip antennas, polar radiation patterns, S_{11} parameter, antenna matching intervals, FEM tool.

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1 Introduction

Patch antennas are built using Printed Circuit Board (PCB) technology, where top or other conducting layers are radiating radio waves to the free space [1], [2]. Early works six decades ago presented their features, behavior, and design techniques [3], [4]. Some of the most important aspects of printed antennas are employed in land and aeronautical applications where it is important to have a low profile, lightweight weight and inexpensive manufacturing techniques for large quantities.

There are a lot of geometric shapes, including polygons like triangles, squares, and rectangles, for at least one patch on the top layer of a PCB [5]. In these cases, there is only one resonant frequency, which can be modeled as a line transmission or cavity [6]. The bandwidth in the frequency domain is normally around 3% or less [7], [8]. The bandwidth of the channels is related to the frequency interval where the S_{11} parameter is equal to -10 dB or less [8].

An additional band can be obtained using a slot in the center of the patch, changing the impedance and frequency response [9].

Other articles show additional techniques for broadband antennas with fractal geometries, shorting pins, or antenna arrays [10], [11], [12].

Many systems require two frequency channels in the terminal equipment for radiocommunication mobile applications, because this kind of system uses full-duplex communication [13]. In other words, the first channel is dedicated to the implementation of the transmission operating mode, and the receiver uses the second channel. The transmission of the mobile stations has a higher frequency, and the receiver normally uses a channel with a lower frequency, but the size of the frequency intervals of the channels can be different.

In Figure 1, a full-duplex mobile radiocommunication system is illustrated, where the mobile terminal station is the source of information and begins the communication using the f_2 carrier for transmission to the media, f_l is the frequency of the receiving carrier.

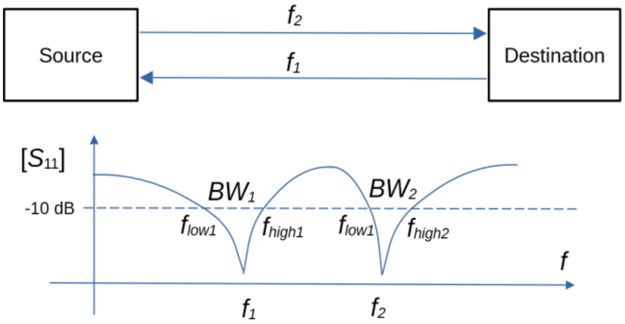

Fig. 1 Frequency intervals for both channels, transmission and reception.
Source: created by the authors

The proposed antenna can adjust the separation of the channels by changing the size of the rectangular patch and the size of the rectangular slot, but a restriction of this geometry is the narrow bands in the two channels.

In this work, a short has been inserted in the corner of the rectangular slot antenna, which is a square in this case. The presence of this element remains the overall performance with a small antenna.

The paper has been structured in the following sections. The first section is dedicated to the microstrip dual-band antenna, and in the second section the model of the antenna is presented. In section three, the main results of the work are presented, and the four sections are related to the conclusions of the paper.

2 Antenna model

In this section, the model of the multi-band patch antenna is explained in detail.

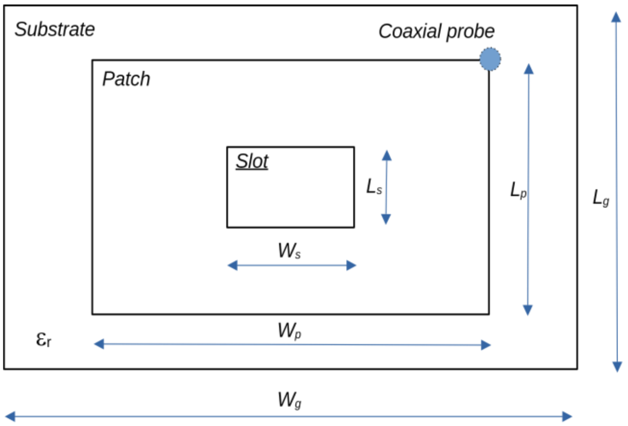

Fig. 2 Front view of the antenna model.
Source: created by the authors

In Figure 2 the top layer of the antenna is illustrated, where W_g is the horizontal size of the ground plane, W_p is the width of the rectangular patch, W_s is the horizontal size of the slot, L_g is the vertical size of the ground plane, L_p is the vertical size of the patch; and L_s is the vertical and horizontal sizes of the square slot.

The main or patch rectangle in the top layer is calculated using the following procedure [1], [2]. The antenna uses the well-known procedure for rectangular patch antennas in the main patch in the PCB top layer.

The horizontal size of the main patch is determined by equation (1). In this equation f_r is the main resonant frequency, Hz; ε_r is the relative permittivity of the substrate; and, v_0 is the velocity of light, m/s.

$$W_p = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

In equation (1) an approximation of a equivalent dielectric constant is introduced to solve the problem in a heterogeneous propagation medium, because the electromagnetic field is propagated in air and substrate.

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

where ε_r is the relative permittivity of the substrate and h is the wideness of the substrate, m.

The edge or fringing effect of the main patch shows a variation of the electric field and it is necessary to adjust the size of the patch using equation (3).

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

The actual size of the rectangular patch considering the edge effect is calculated using equation (4).

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

The frequency of the corresponding mode is determined by equation (5), where m, n, and p, represent the number of half-wavelength sizes of the electric field along the h, L_p and W_p.

$$f_{mnp} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{h}\right)^2 + \left(\frac{n\pi}{L_p}\right)^2 + \left(\frac{p\pi}{W_p}\right)^2} \tag{5}$$

The main mode in the cavity of the rectangular patch antenna is TM_{010}, which corresponds with the cut frequency of the antenna_see Figure 3.

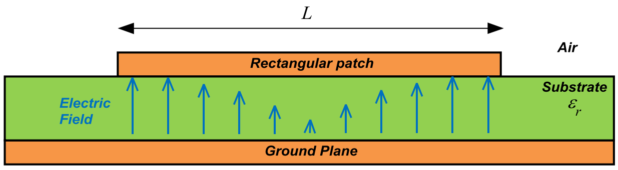

Fig. 3 Electric Field in the mode TM_{010}.
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The size of the slot can be optimized to get the frequencies of the two channels 1 and 2 in the full-duplex system. The recommended interval value of the square side is from 1mm to 10 mm.

On the other hand, the size of the ground layer modifies the frequency response of the antenna significantly. In this work, a new k_{gp} factor is introduced with the aim of analyzing the effect produced with the variation of this parameter, see (6).

$$L_p = k_{gp} L_p \tag{6}$$

3 Results

In this section, some of the most important results of the paper are shown, where the performance of the antenna is evaluated in the frequency domain and the radiation pattern.

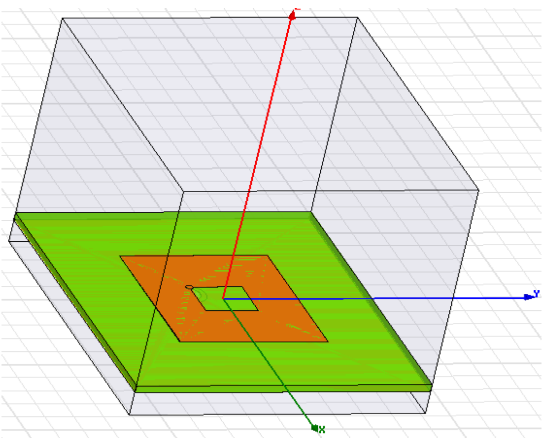

Fig. 4 Antenna model in HFSS.
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In Figure 4, the antenna model is plotted in the simulation process. All the simulation results were obtained using the electromagnetic software High Frequency Simulation Software (HFSS).

In Table 1, we can see the effect of the variation of the ground layer size, where both bands are tabulated using the parameter $[S_{11}]$ in dB.

Table 1
Frequency Response of the Antenna

	k_{gp}	f_1 GHz	BW_1 %	f_2 GHz	BW_2 %	$[S_{11}]$ dB (f_1)	$[S_{11}]$ dB (f_2)
1	2.00	1.91	0.9948	2.42	2.1901	-11.33	-20.18
2	2.20	1.84	1.1141	2.36	1.8432	-12.23	-16.99
3	2.40	1.85	1.3784	2.32	1.9828	-15.18	-23.05
4	2.60	1.81	1.105	2.28	1.8421	-13.92	-20.6

Source: created by the authors

Figure 5 shows the frequency of the channels and their bandwidth for the two bands. One of the best values of the ground plane with a k_{gp} equal to 2.4.

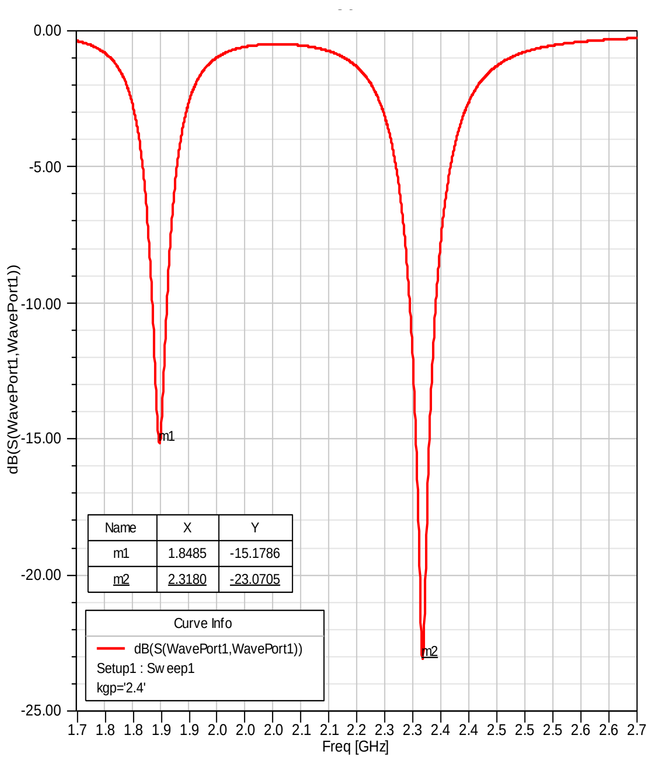

Fig. 5. Frequency response of the antenna.
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In Figure 6, we can see the dependence of the ground plane size, where k_{gp} = 2.0, 2.2, 2.4.

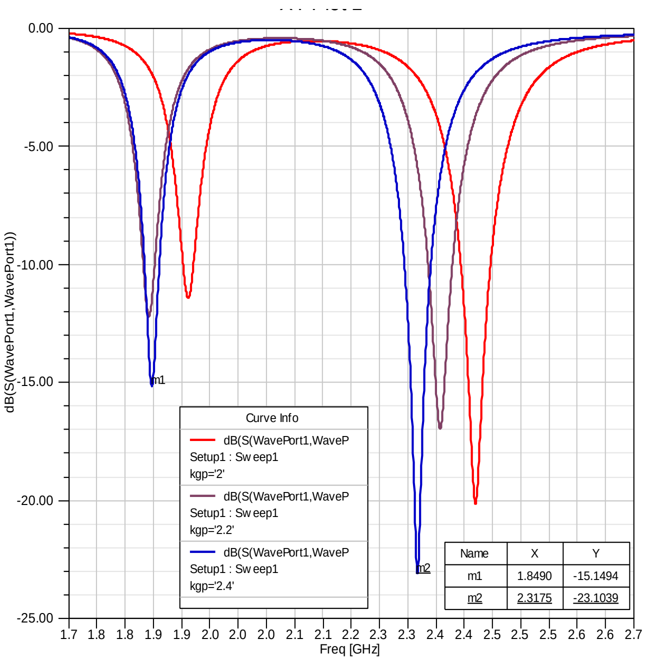

Fig. 6. Frequency response for three values of k_{gp}.
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The resulting antenna pattern obtained with a k_{gp}= 2.4 is plotted in Figure 7. In this consideration, the main disadvantage of a large slot is the antenna gain reduction in comparison with a standard RMA.

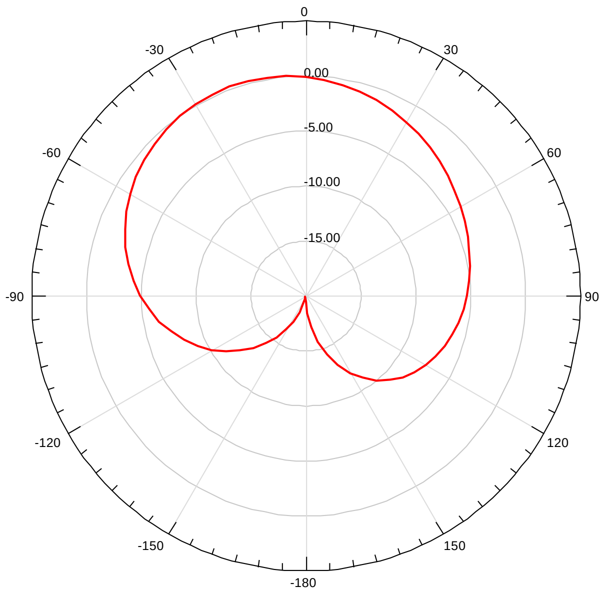

Fig. 7. Polar pattern of the antenna.
*Source: created by the authors*The antenna pattern does not change significantly in comparison with the frequency response. This result can be analyzed with Figure 8, where k_{gp} = 2.0, 2.2, 2.4.

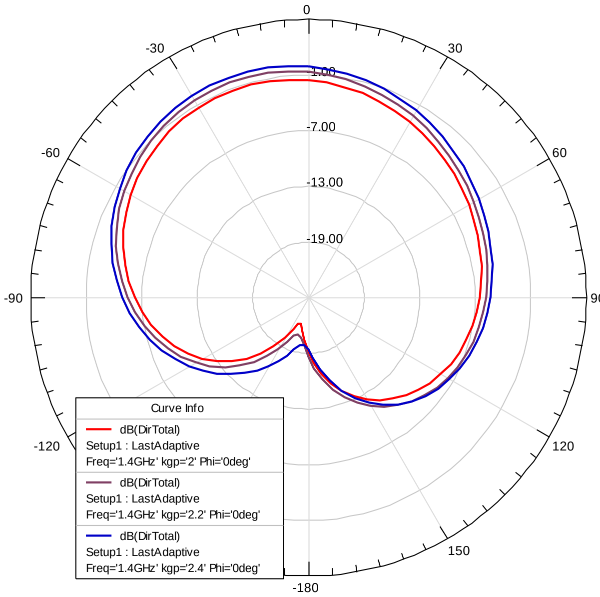

Fig. 8. Antenna pattern with k_{gp} = 2.0, 2.2, 2.4.
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In Figure 9, the Electric Field is plotted, and it is clear that the storage of this field between the main patch of the antenna and the ground layer, but the size of the slot reduces the magnitude of the field.

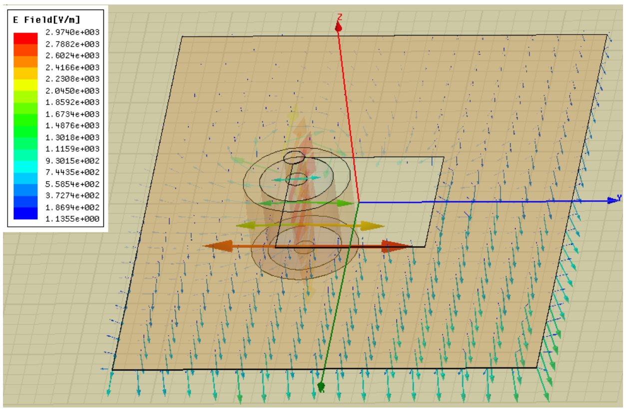

Fig. 9. Electric Field of the antenna.
*Source: created by the authors*In Figure 10, the Magnetic Field is shown, and the magnitude of the field is also narrowed down.

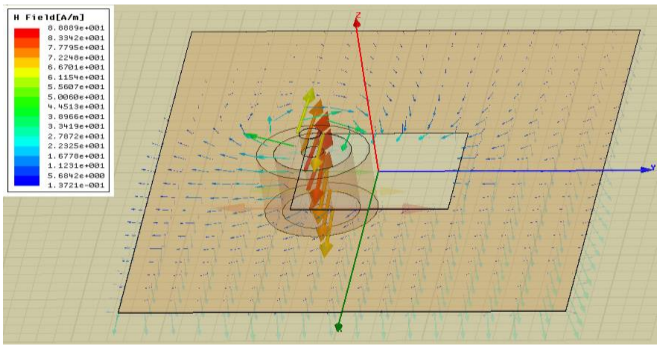

Fig. 10. Magnetic Field of the patch antenna.
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The front layer of the antenna designed and simulated is illustrated in Figure 11, where the shorting pin is located in a slot corner and is connected to the back layer.

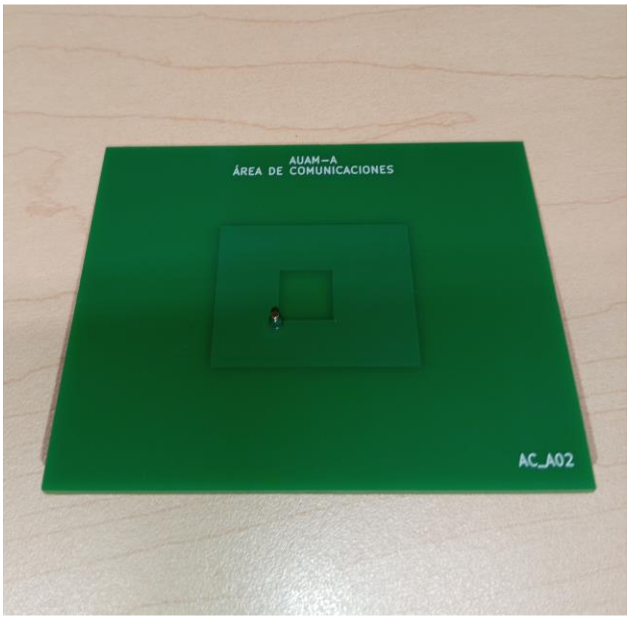

Fig. 11. Front layer of the slotted rectangular antenna.
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The back view of the antenna designed and simulated is shown in Figure 12.

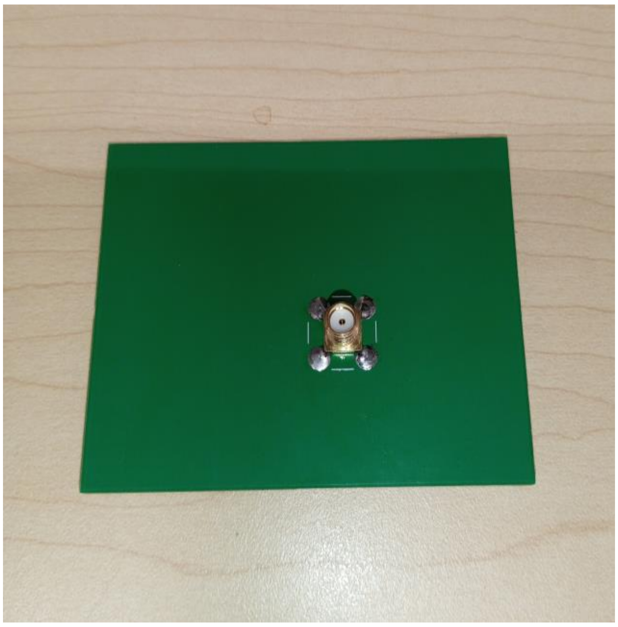

Fig. 12. Back view of the slotted rectangular antenna.
*Source: created by the authors*The most important experimental results are presented in Figure 13 and Figure 14, where the first and second bands of the antenna are plotted.

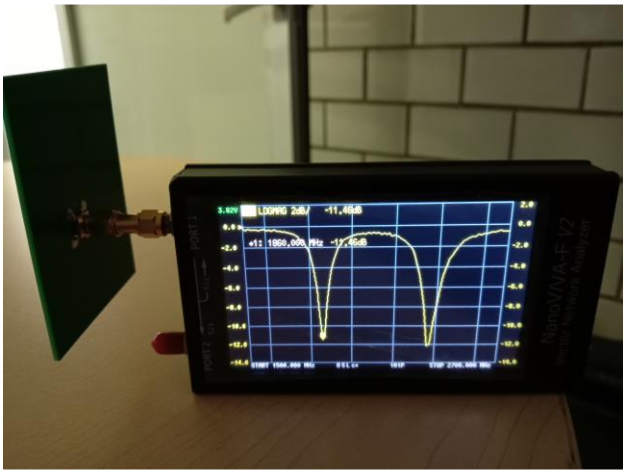

Fig. 13. First band detail in the frequency response of the antenna.
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The first band has a resonant frequency at 1,860 MHz, and the second one is located at 2,364 MHz. The bandwidths of the antenna are narrow, and the [S_{11}] parameters are nearly equal to -12 dB.

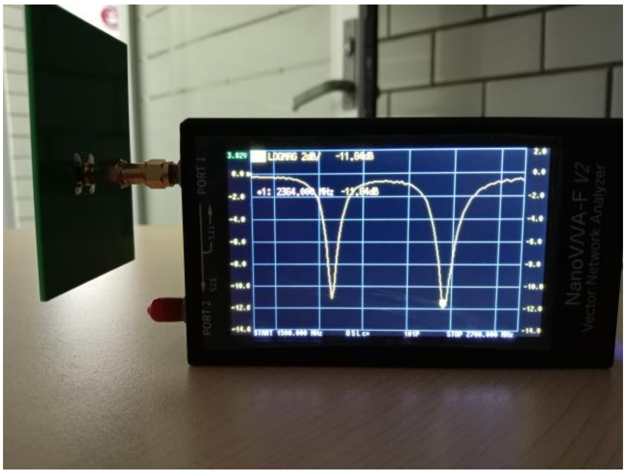

Fig. 14. Second band detail in the frequency response of the antenna.
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4 Conclusion

The dual-band slotted patch rectangular antenna was designed, simulated, implemented, and measured.

The dependence of the ground plane on the frequency response is high, and it is one of the most important drawbacks of the antenna; the other disadvantage is the antenna gain reduction, especially with a large slot.

There are other possibilities for implementing slot geometry that can be used and/and the insertion of shorting pins.

The advantages of the two-band antenna are the low size in comparison with microstrip antenna arrays and the easy fabrication for a large production [14], [15], [16], [17]. Besides, this kind of antenna does not require a complex feeding line transmission, balun, or transformer [18], [19].

The antenna has two narrow bands with return losses approximately equal to 12 dB.

Experimental results and a wider variation of the slot geometry can enhance the performance of the antenna. At this moment, both considerations are considered.

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

- Mario Reyes-Ayala: Formal analysis, investigation, methodology, writing – original draft, conceptualization, investigation formal analysis, writing, review and editing.
- Edgar Alejandro Andrade-Gonzalez: Project administration, resources, review, validation.
- Sandra Chavez-Sanchez: Visualization, review validation.
- Rene Rodriguez-Rivera: Visualization, review validation.
- Hilario Terres-Peña: Supervision, validation, review.
- Gerardo Salgado-Guzman: Validation, review.
- Jose Ignacio Vega-Luna: Validation, review.

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Conflict of Interest

The authors have no conflicts of interest to declare.