Microstrip GPS Circular Antenna for Terrestrial Transportation Systems

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Abstract: - In this paper, the design, implementation, and evaluation of a microstrip circular antenna is presented and analyzed. This antenna has two resonant frequencies, which are used in the Global Positioning System (GPS). The antenna was built in a low-cost Printed Circuit Board (PCB) with a FR-4 substrate. The top layer of the PCB includes two slots in the main circular patch, which normally is used in a single carrier reception. The radiation pattern of the antenna shows a wide main lobe in the vertical axis, intending to obtain line-of-sight communication links with five or more GPS satellites.

Key-Words: - Microstrip antenna, circular patch antenna, GPS, PCB, multi-band antenna, slot antenna, resonant frequency.

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1 Introduction

Global Positioning System (GPS) is a 32-satellite constellation in a six-plane Medium Earth Orbit (MEO) that gives time information and geolocation around the globe. GPS is used by many transportation systems anywhere, [1].

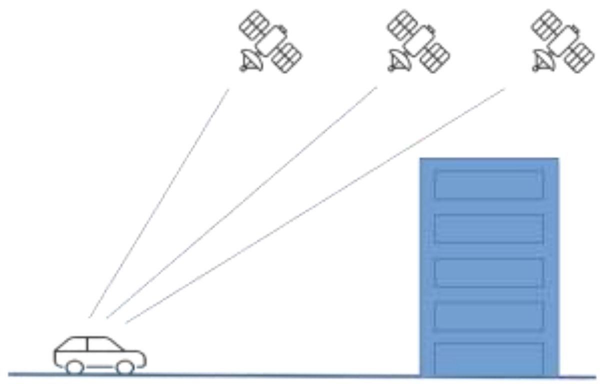

Fig. 1: Use of GPS in the urban environment

In the urban environment, the Line Of Sight (LOS) path is frequently lost, as a consequence of the presence of buildings or other large-size objects, especially if the elevation angle of the link is lower than 30 degrees, [2]. A very wide major lobe of the antenna is placed on the top of a terrestrial vehicle to achieve the necessary power in a GPS link budget (Figure 1).

In this paper, a microstrip antenna with a circular patch and two internal slots is proposed to enhance the frequency response for two matching intervals of GPS receivers. Each matching interval corresponds to a resonant frequency (L1 and L2 carriers). L1 (1.57542 GHz) is used in civilian mobile communications and L2 (1.22760 GHz) is dedicated to military applications. L3, L4, and L5 are only related for military purposes and these carriers are not employed in this paper.

The use of slots increases the number of resonant frequencies producing a higher bandwidth in single band antennas or multiband antennas, [3], [4], [5]. In this case, the size of the circular patch in the top layer determines the resonant frequency of the L2 carrier, and the additional slots can stabilize the frequency response and create a resonant frequency for the L1 carrier.

2 Problem Formulation

Using the typical circular patch approach presented in [6], [7], [8], [9] and [10], we can determine the geometry of the antenna with the equations (1) and (2), that is shown in Figure 2.

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \qquad (1)$$

$$F = \frac{8.791 \times 10^9}{f_r\sqrt{\varepsilon_r}} \qquad (2)$$

Where f_r is the resonant frequency for the L2 carrier; ε_r is the dielectric constant; is the thickness of the PCB substrate; and, a is the radius of the circular patch.

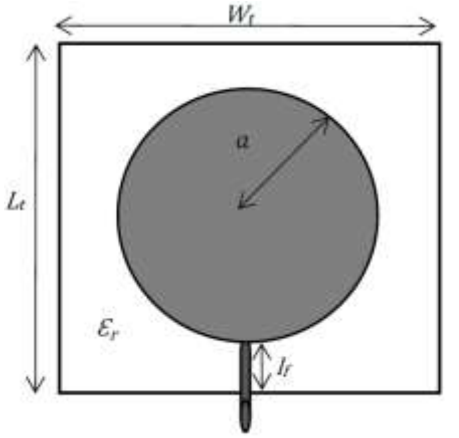

Fig. 2: Microstrip circular antenna

The impedance and line transmission for matching the circular patch can be calculated using the very well-known procedure for regular shape microstrip antennas, [11], [12], [13], [14], [15], [16], [17]. In this work, the circular shape was proposed to obtain a more symmetric main lobe.

Table 1 summarizes the main parameters of the antenna. The sizes of the slots were computed using dipoles and rectangular microstrip antennas, [18], [19], [20], [21].

Table 1. Antenna Model

Model Parameters		Size (mm)
Width of the Ground Plane	⍰⍰	90
Length of the Ground Plane	⍰⍰	90
The radius of the patch	⍰	32.3
Width of the feeder	⍰⍰	0.3
Length of the feeder	⍰⍰	26
Width of the first slot	⍰⍰1	1.2
Length of the first slot	⍰⍰1	36.4
Width of the second slot	⍰⍰2	12
Length of the second slot	⍰⍰2	14

Other shapes like triangles or bowtie antennas have a larger bandwidth, but their main lobes are asymmetric, [22]. The resulting geometry of the antenna can be seen in the Figure 3.

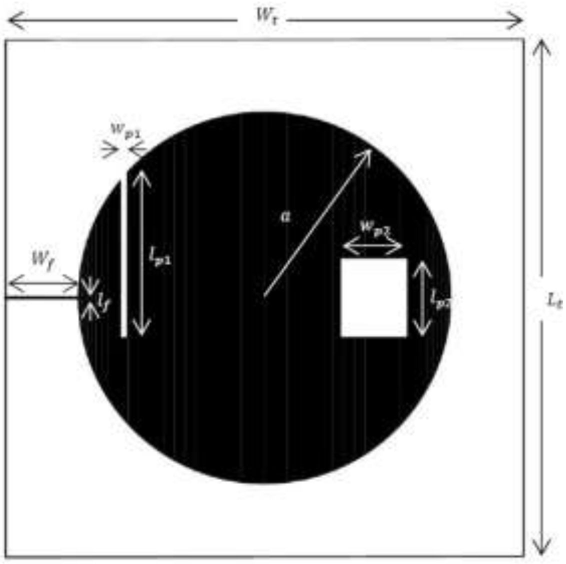

Fig. 3: The final appearance of the antenna with the insertion of two slots

3 Results

The antenna was simulated using the HFSS software, which is a Finite Element Method (FEM) that is one of the main choices in microstrip antennas, [23].

Figure 4 illustrates the model that was simulated with an FR-4 substrate. The orientation of the model produces the main lobe in the vertical axis.

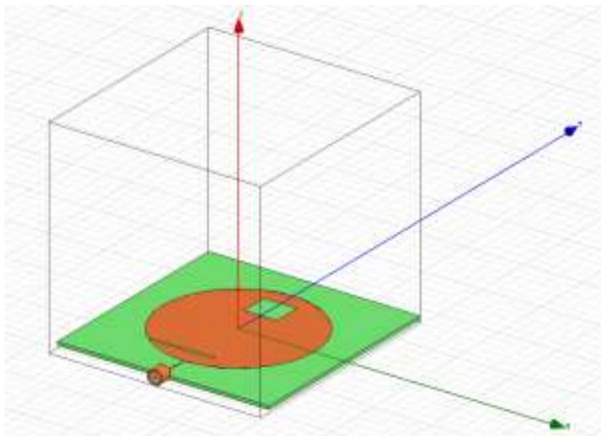

Fig. 4: Simulated model using HFSS

The carriers L1 and L2 of the GPS system were obtained after the simulation of the S_{11} parameter (Figure 5).

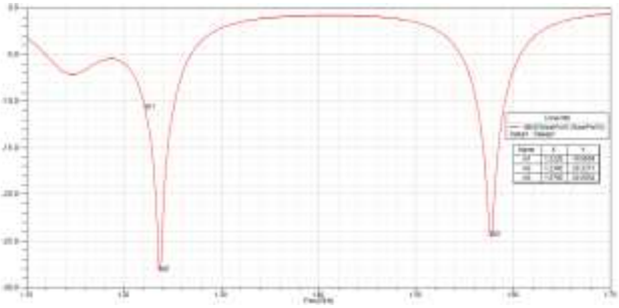

Fig. 5: Return losses of the antenna obtained by simulation

The numeric simulation results are shown in the Figure 6, where antenna directivity is included, and illustrated in the following figures (Table 2).

Table 2. Simulation Results

Parameter	Description
Resonant frequency (L1)	1.5760 GHz
Resonant frequency (L2)	1.2360 GHz
Matching interval (L1)	1.9%
Matching Interval (L2)	2.6%
S_{11} (L1)	24.6054 dB
S_{11} (L2)	28.3271 dB
Bandwidth (L1)	300 MHz
Bandwidth (L1)	320 MHz
Antenna directivity	2.6003 dB

The insertion of the slots reduces the directivity, which is illustrated in the Figure 6.

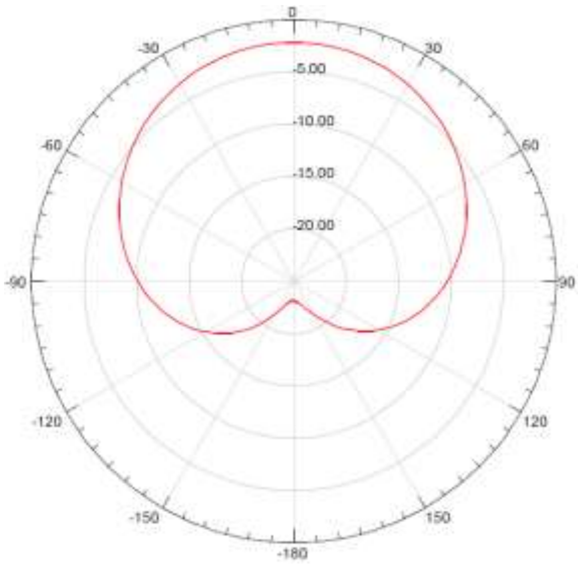

Fig. 6: Directivity pattern of the antenna (elevation angle view)

The 3D antenna pattern shows the directivity of the structure, which is approximately 2.6 dB (Figure 7).

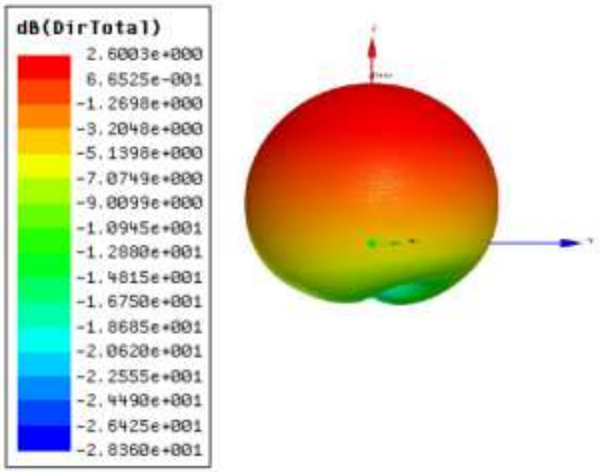

Fig. 7: Tridimensional antenna pattern for the directivity

After the simulation stage, the antenna was built with a numerical tool with an accuracy of +/- 0.01 mm, which is necessary to get a good approximation in comparison with HFSS results.

The antenna is displayed in Figure 8, where the line transmission feeder of the antenna was designed to match de circular patch with the measurement equipment.

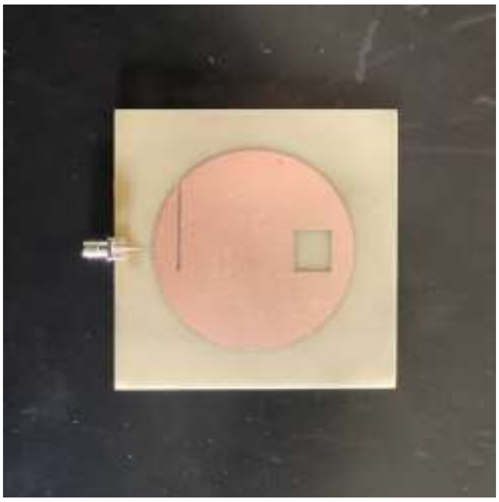

Fig. 8: Circular antenna built by CAD/CAM methods

The same parameters obtained by simulation were already measured using a Network Analyzer (FieldFox). In the Figure 9, we can see a quite similar plot presented before in simulations results.

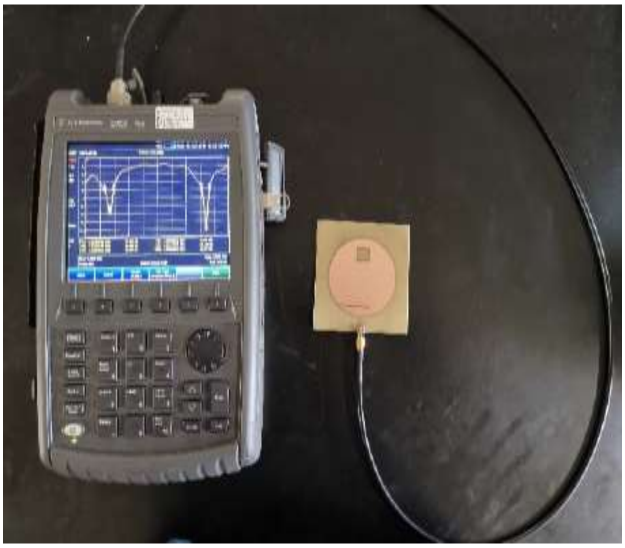
Fig. 9: Return losses obtained experimentally.

The same results were measured and saved in the FieldFox and it is presented in Figure 10.

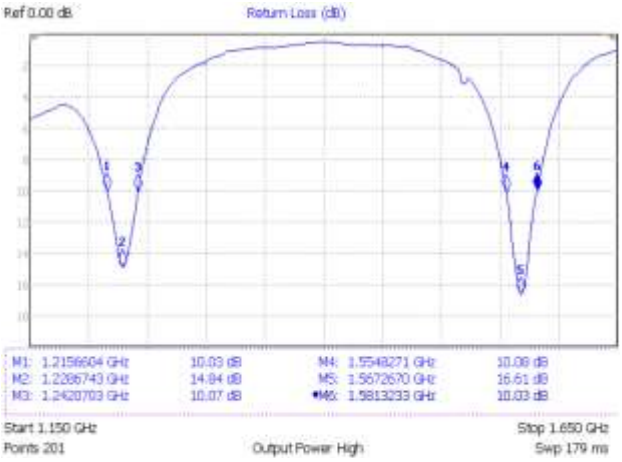

Fig. 10: Screen of the return losses obtained with a FieldFox

The parameters obtained with the FieldFox are summarized in Table 3, where matching intervals are estimated using the markers shown in Figure 10.

Table 3. Frequency Response Results

Parameter Description	
Resonant frequency (L1)	1.5672 GHz
Resonant frequency (L2)	1.2286 GHz
Matching interval (L1)	1.6%
Matching interval (L2)	2.1%
S_{11} (L1)	16.61 dB
S_{11} (L2)	14.84 dB
Bandwidth (L1)	260 MHz
Bandwidth (L2)	260 MHz

The last measurement was the antenna pattern, which was obtained with a planar scanner that measured the near field of the antenna. This equipment is employed with a Personal Computer (PC) and a FieldFox Network Analyzer (NA). The far field of the antenna is computed by interpolation in the PC.

The RFxpert scanner is provided by EMSCAN and gives a very good approximation of the far field in small and planar structures.

In Figure 11, the configuration of the equipment is illustrated, where the communication is performed by an ethernet or USB protocol.

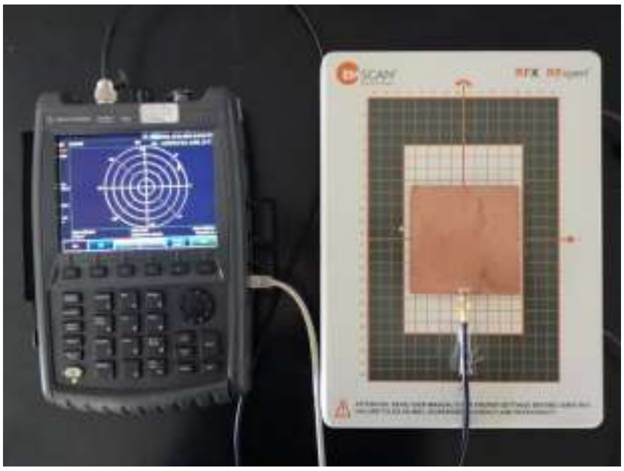
Fig. 11: Measurement using a RFxpert by EMSCAN

In Figure 12, we can see two azimuthal views 0º (yellow) and 90º (red) plotted in a polar graph.

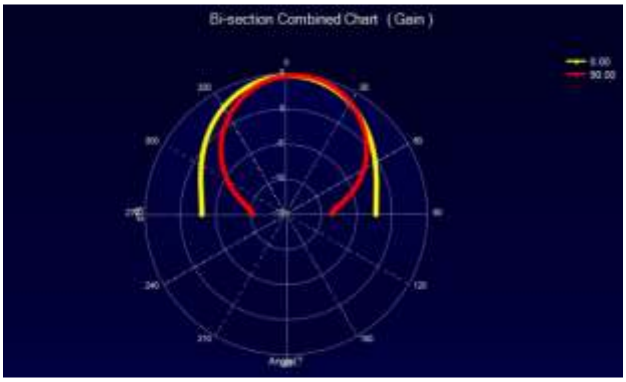

Fig. 12: 90º and 0º Azimuthal views of the antenna pattern

The tridimensional antenna pattern is illustrated in Figure 13, where it is clear the asymmetry of the main lobe.

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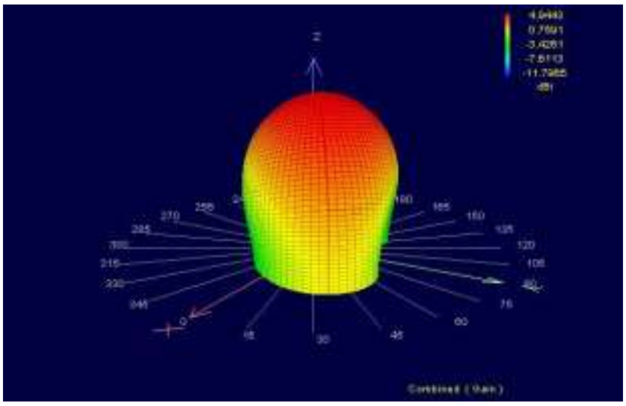

Fig. 13: 3-D antenna pattern

4 Conclusion

In this work, a microstrip circular antenna for GPS receivers was carried out. Analysis of regular shapes of the microstrip antennas for mobile communications was performed, and the insertion of two slots was used to have two resonant frequencies for L1 and L2 GPS most important carriers in civilian applications. Other regular structures modify the impedance, symmetry of the antenna patterns, bandwidth, or size of the antenna, that is the reason to use a circular patch, [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34].

The FR-4 substrate was selected to reduce the price of the manufacturing process. It is necessary to explain that this antenna is used for educational purposes.

Right now we are employing this kind of antenna with a regular method of manufacturing, and it is important to say that the results are quite similar.

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

- Ignacio Antonio Hidalgo García: Formal analysis, investigation, methodology, writing – original draft
- Mario Reyes-Ayala: 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
- Jose Ignacio Vega-Luna: Validation, review

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Conflict of Interest

The authors have no conflicts of interest to declare.