Development of an UHF 2×2 Microstrip Antenna Array for Nano-Satellites

Juner M. Vieira, Marcelo P. Magalhães, Marcos V. T. Heckler, João C. M. Mota and Antonio S. B. Sombra

***Abstract*—This paper presents the study of a microstrip antenna to be installed onto meteorological nano-satellites. In order to increase the effective ground plane so as to improve the front-to-back ratio and the gain, metallic strips were attached to the antenna ground plane. The performance was evaluated using different types and sizes of metallic strips. An improvement in the front-to-back ratio whilst keeping good axial ratio performance was observed. For validations, a prototype was manufactured and the measured results compared to the simulations.**

***Index Terms*—Microstrip antenna, antenna array, meteorological nano-satellite, circular polarization.**

I. Introduction

The CONASAT program was created by the National Institute for Space Research (INPE) and aims at using nano-satellites as a new solution for the Brazilian System for Meteorological Data Acquisition (SBCD). The CONASAT system provides a new and cost effective approach for environmental monitoring. The nano-satellites will work as data relay of meteorological informations collected by the data collecting platforms (PCDs) installed in remote areas of Brazil, where wireless communication is not possible. The size of these nano-satellites is $8U$, where U is the standard cubesat dimension developed by the Space Flight Laboratory of Toronto University (a cube with 20 cm of edge size and a maximum mass of 10 kg)[2]. In order to increase the area for installing the solar panels, the nano-satellite will be designed with four articulated flaps. Since this system is planned to operate in the Low-Earth Orbit (LEO), the use of a constellation of nano-satellites is needed to cover the whole Brazilian territory and to improve the revisiting time [3].

For aerospace applications, the microstrip antenna technology has some advantages, such as light weight, compactness and design flexibility [4]. In the literature, some techniques to design microstrip antennas for nano-satellites can be found. The authors of [5] suggest a microstrip antenna model that operates in S-band for applications such as telemetry and high speed data transmission. In [6], the design of antennas with triangular patches for hexagonal shaped nano-satellites is described. In [7] and [8], an analysis of the radiation characteristics of low-cost and circularly polarized microstrip antennas is presented. Further geometries of microstrip antennas for circular polarization are presented in [9]-[10].

The analysis of antenna arrays for nano-satellites using Thermoset Microwave Materials (TMM) with different dielectric constants has been reported in [11]. The proposed array was designed to operate in receiving mode at 401 MHz, which is the operating frequency of the uplink channel of the SBCD.

Due to the small electrical dimensions of the nano-sat, in comparison to the operating wavelength, the radiation pattern presents low front-to-back ratio. This results in a reduction of the antenna gain in the direction of interest. In order to present a possible solution to compensate this limitation, this paper presents the development of microstrip antennas with extended effective ground plane. This feature is obtained by attaching metallic rods or strips to the antenna. The array was designed and analyzed through electromagnetic simulations in the Ansys HFSS software [12]. The paper is divided in the following sections: section II presents the design specifications of the microstrip antenna, along with a discussion on its geometry and its main characteristics. Section III describes the antenna design without GND extensions. Section IV presents the results after the inclusion of metallic rods or strips into the antenna structure. Section V presents the simulations results for the UHF array installed onto the nano-satellite. Finally, section VI presents the final remarks.

II. Design Specifications

The operation scenario of the data acquisition system is shown in Figure 1. The constellation of nano-satellites will serve as a relay for meteorological data, which are collected by the PCDs. The uplink is allocated at 401 MHz and the downlink in the S-band.

Due to the large wavelength, UHF antennas for nano-satellites are implemented normally as monopoles. However, they do exhibit low gain, hence decreasing the signal-to-noise ratio at the receiver installed in the nano-satellite. In order to increase the gain of the UHF antenna, a microstrip antenna array has been designed and mounted onto the nano-satellite structure.

The following specifications apply for the UHF antenna: right-hand circular polarization with axial ratio lower than 6 dB, input impedance matched to $50\ \Omega$ and bandwidth of

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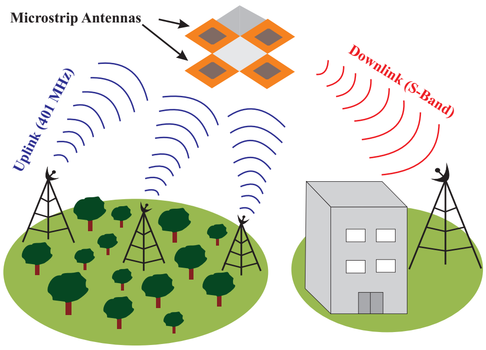

Fig. 1. Scenario for the meteorological nano-satellite.

4 MHz [13]. The antenna dimensions must be smaller than 19 cm due to the satellite size of 20x20x20 cm. Considering the wavelength of operation, this represents a small electric dimension, which implies that the main design challenge is to obtain satisfactory performance with a small electrical geometry. For this case, in order to reduce the patch, the use of dielectric substrates with high dielectric constants is recommended [14].

III. Standard Antenna Design

Circular polarization can be obtained with the use of a corners-truncated patch [4], [15]. In order to achieve the desired bandwidth, the substrate used is thick and the antenna is fed with a microstrip line with electromagnetic coupling. The microwave laminate used is Taconic CER-10 [16], which has dielectric constant of $\varepsilon_r = 10.2$ and thickness of 3.18 mm. In order to obtain the desired bandwidth, one of such layer has been employed between the feed line and the ground plane (GND) and another layer of the same thickness layer between the line and the patch. All the layers are glued with the prepeg Fast Rise 27 (FR27) [17], which has dielectric constant of $\varepsilon_r = 2.61$ and thickness of 0.162 mm. The cross-sectional view of the structure is sketched in Figure 2. As shown in Figure 3, the design parameters for this antenna are the patch width W, the width of the feed line W_{Z0}, the length of the line below the patch L and the size of the truncation A.

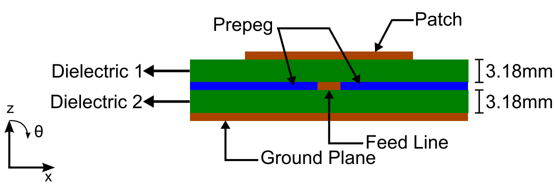

Fig. 2. Cross-sectional view of the designed antenna.

After the optimization of axial ratio and impedance matching, the following dimensions were obtained: $W = 118.7$ mm, $L = 55.9$ mm, $W_{Z0} = 0.35$ cm and $A = 7.063$ mm. The results for axial ratio and radiation pattern are shown in Figures 4 and 5, respectively. The maximum gain obtained for this antenna was of 1.73 dBi and the front-to-back ratio obtained was only 3.82 dB.

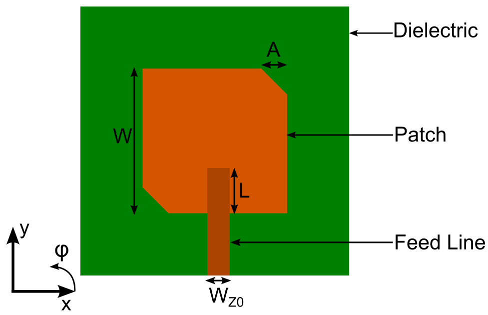

Fig. 3. Schematic top view of the designed antenna.

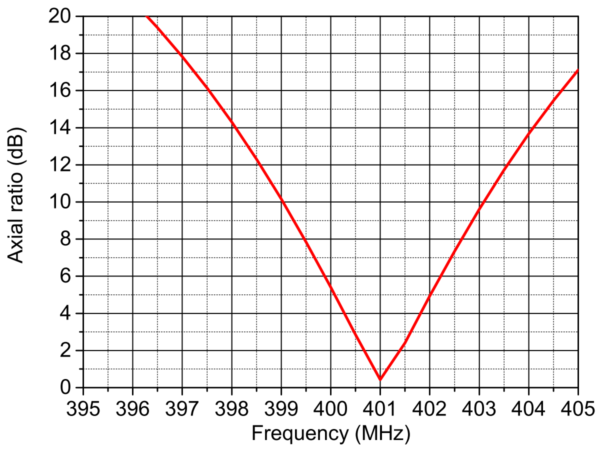

Fig. 4. Axial ratio as a function of the frequency for the standard antenna, in $\theta = \phi = 0°$.

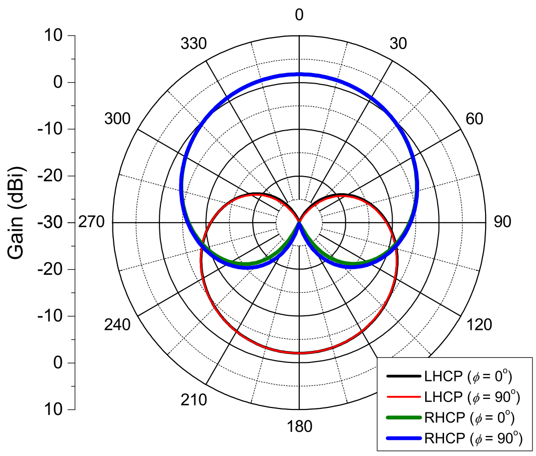

Fig. 5. Gain pattern for the standard antenna.

A. Validation of the antenna design

For validation of the simulations for the standard antenna, a prototype was manufactured. A photo of the prototype is shown in Figure 6.

For building the prototype, no special machine for gluing the laminates was available. By the instrumentation used for this procedure, the pressure has not been applied uniformly onto the whole antenna surface. The consequence of this was

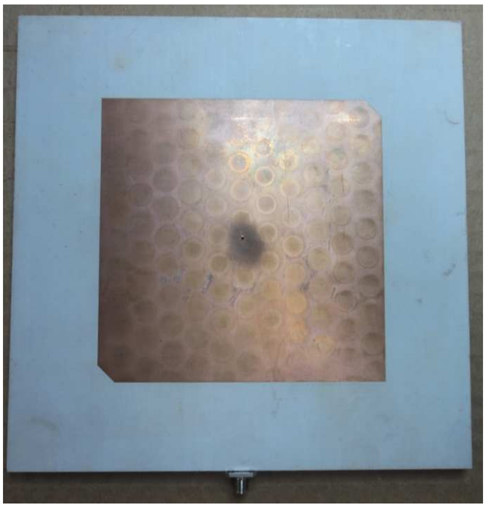

Fig. 6. Top view of the the prototype standard antenna.

that the prepeg did not glued completely both laminates, so that an air layer remained inside the structure. This is clearly shown in Figure 7. This makes the effective dielectric constant to deviate from the nominal value, hence shifting the operating frequency of the prototype. Thus, a new simulation included an air layer with thickness of 0.045 mm was performed. The comparison between measured and computed $S11$ is shown in Figure 8. As it can be observed, the simulation result including an air layer reproduces well the measured curve.

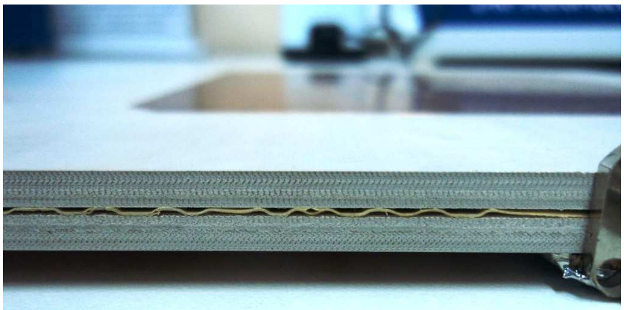

Fig. 7. Cross-sectional view of the prototype standard antenna.

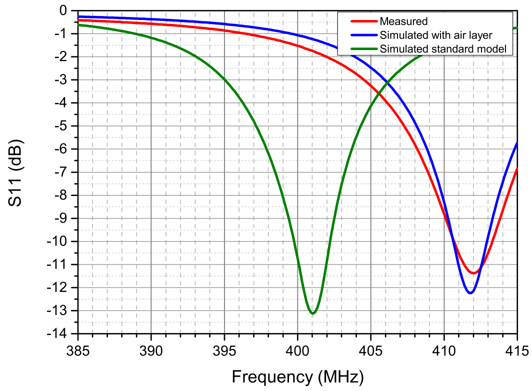

Fig. 8. Comparison between measured and computed results.

IV. Antenna Design with Extended Ground Plane

The previous section presented results for a standard circularly polarized microstrip antenna. Due to the size of the nano-satellite, the antenna GND has been chosen to be 19×19 cm. Since this is much smaller than the operating wavelength in free space, the gain pattern shown in Figure 5 exhibits large back radiation. Due to this characteristic, the antenna gain is much lower than it is normally expected for a standard microstrip antenna, since large amount of power in comparison to the power level emitted in the antenna boresight is radiated backwards. The only way to minimize this problem is to increase the ground plane size. However, this makes the antenna larger than the specified maximum dimensions and heavier than it is normally desired for nano-satellites.

One way to minimize the back radiation is to implement an extended GND by the use of metallic rods, which should be opened after the nano-satellite is launched. Three types of metallic structures have been considered: cylindrical rods, metallic strips and a metallic fence.

A. Extended GND with Cylindrical Rods

Initial simulations were performed considering that telescopic metallic rods could be used to implement the extended GND. This topology is sketched in Figure 9, where the rods have been attached to each GND edge. In order to assess the number and length of the rods that should be used to obtain acceptable results, the following cases have been simulated: 2 or 4 rods attached to each GND edge with lengths of 4 cm, 6 cm and 8 cm. The rods have been considered to be 1.5 mm radius.

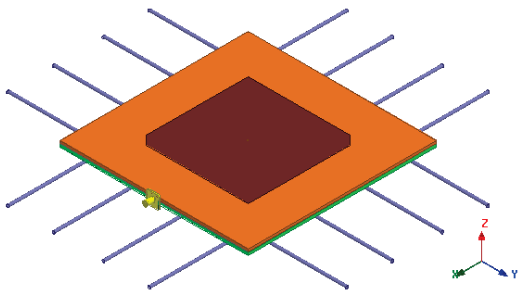

Fig. 9. Designed antenna with cylindrical rods.

The presence of the metallic rods shifted the operating frequency of the antenna. After the redesign, the following dimensions were obtained: $W = 118.91$ mm, $L = 56.15$ mm, $W_{Z0} = 0.35$ cm and $A = 8.74$ mm. reflection coefficient and axial ratio were plotted and are shown in Figures 10 and 11. Also, the gain patterns were computed and the best results are shown in Figures 12 and 13 for two and four rods at each edge of the GND, respectively. The gain achieved for each case is presented in Table I. The best performance in terms of gain has been obtained with four 8-cm long rods attached to each GND edge.

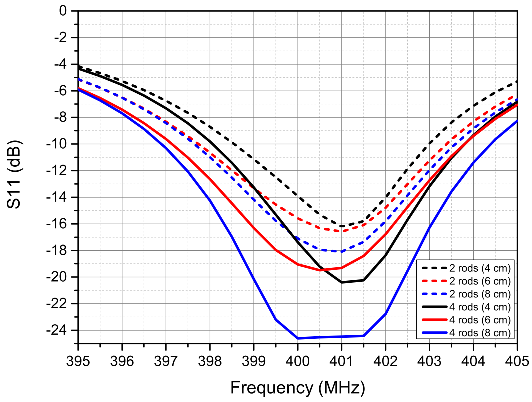

Fig. 10. Reflection coefficient as a function of the frequency for all cases employing cylindrical rods.

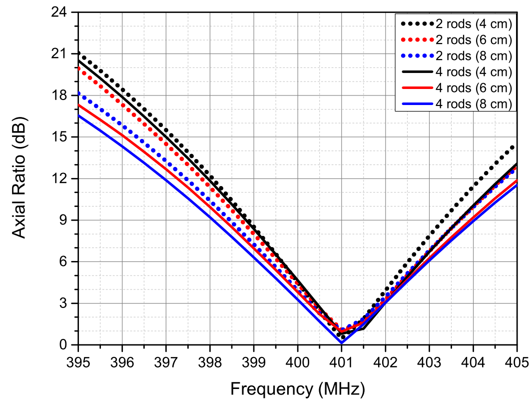

Fig. 11. Axial ratio as a function of the frequency for all cases employing cylindrical rods.

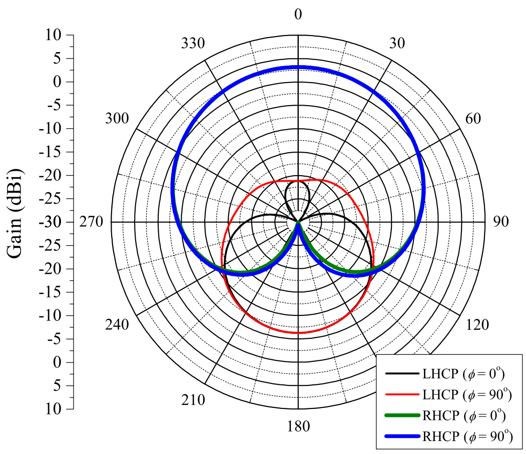

Fig. 12. Gain pattern for the antenna with two 8-cm cylindrical rods attached to each GND edge.

B. Extended GND with Metallic Strips

Metallic cylindrical rods can be used only if a telescopic structure, similar to an FM antenna of a portable radio, is

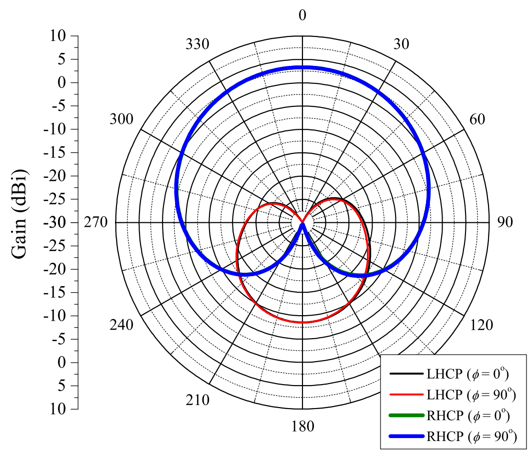

Fig. 13. Gain pattern for the antenna with four 8-cm cylindrical rods attached to each GND edge.

TABLE I
MAXIMUM GAIN FOR DIFFERENT LENGTHS AND NUMBERS OF CYLINDRICAL RODS.

Length	Number	
	2 Rods	4 Rods
4 cm	2.58 dBi	2.92 dBi
6 cm	3.05 dBi	3.33 dBi
8 cm	3.15 dBi	3.29 dBi

used. This demands the use of machines to open the rods. If we consider 4 rods for each of the 4 antenna edges, a total of 16 such machines will be needed. This becomes a bulky structure that is supposed to be used only in the first minutes after the satellite is launched. Moreover, it results in an increase of the total weight of the nano-satellite, which is, along with the other disadvantages, unacceptable.

An alternative approach is to replace the cylindrical rods by flexible metallic strips, similar to metallic measuring tape. In this case, the strips can be folded into the satellite before launching, and are automatically opened when the antenna is deployed, hence saving space and weight.

The extended GND with metallic strips is sketched in Figure 14. The strips have been considered to be 1.3 cm wide. Also for this case, two and four strips were attached to each side of the GND and their length was varied for 4 cm, 6 cm and 8 cm. After a new optimization of the antenna dimensions and the attachment of the strips, the following dimensions were obtained: $W = 118.77$ mm, $L = 55.9$ mm, $W_{Z0} = 0.35$ cm and $A = 8.53$ mm. The resulting reflection coefficient and axial ratio are shown in Figures 15 and 16. The gain patterns for the best cases are shown in Figures 17 and 18 for two and four strips attached to each side of the antenna, respectively. The maximum gains for each case are presented in Table II. The best performance in terms of gain has been obtained for 8-cm long strips and resulted in 3.32 dBi.

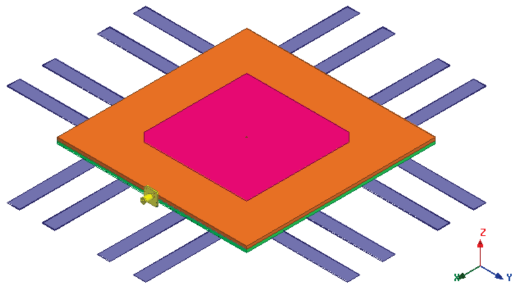

Fig. 14. Designed antenna with metallic strips.

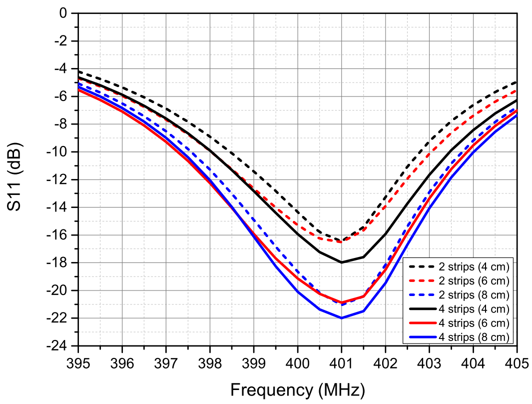

Fig. 15. Reflection coefficient as a function of the frequency for all cases of the metallic strips.

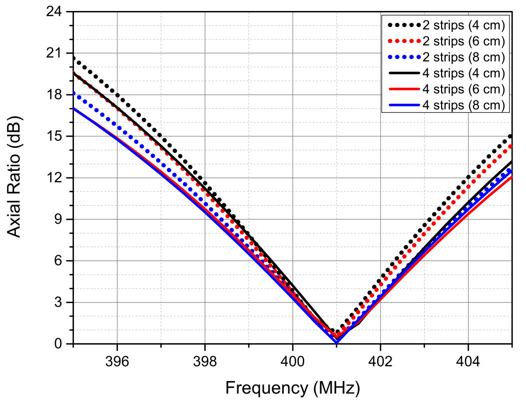

Fig. 16. Axial ratio as a function of the frequency for all cases of the metallic strips.

C. Extended GND with a Metallic Fence

The study of metallic strips to increase the effective ground plane was presented in the previous subsection, showing a better performance than compared with the standard model of microstrip antennas (without strips). In order to improve the antenna array performance, two new antenna models

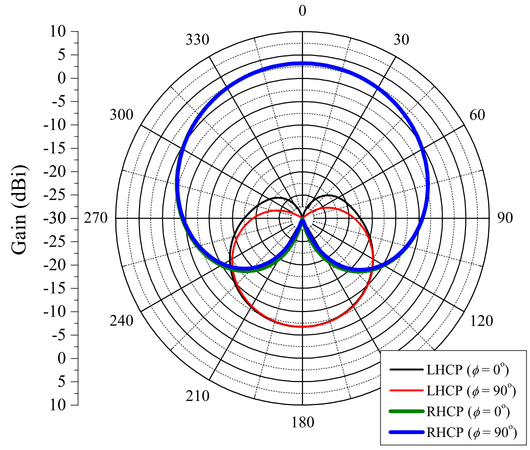

Fig. 17. Gain for the antenna with two metallic strips and length of 8 cm.

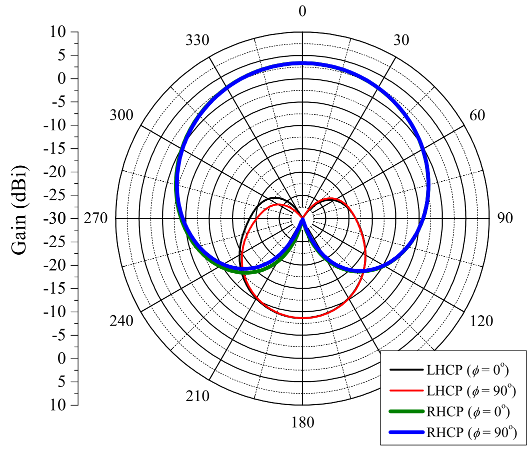

Fig. 18. Gain for the antenna with four metallic strips and length of 8 cm.

TABLE II
MAXIMUM GAIN FOR DIFFERENT LENGTHS AND NUMBERS OF STRIPS.

Length	Number	
	2 Strips	4 Strips
4 cm	2.64 dBi	3.12 dBi
6 cm	2.97 dBi	3.29 dBi
8 cm	3.18 dBi	3.32 dBi

using a metallic fence composed of crossed metallic strips were designed. Figure 19 shows the structure adopted for the metallic fence. For this approach, two different sizes L_{fence} were considered: 8 cm and 10 cm.

Some additional simulations were done to optimize the antenna performance after the fence was attached to the GND. The following dimensions were obtained: $W = 119.26$ mm, $L = 55.9$ mm, $W_{Z0} = 0.35$ cm and $A = 8.5$ mm The resulting reflection coefficient and axial ratio are presented in Figures 20 and 21, respectively.

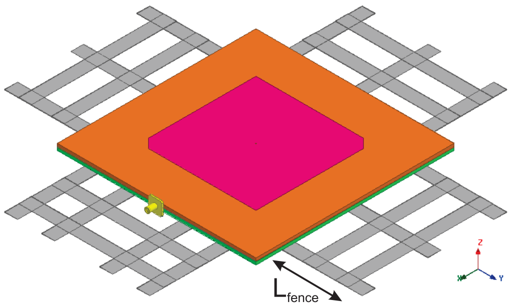

Fig. 19. Antenna structure using metallic fence.

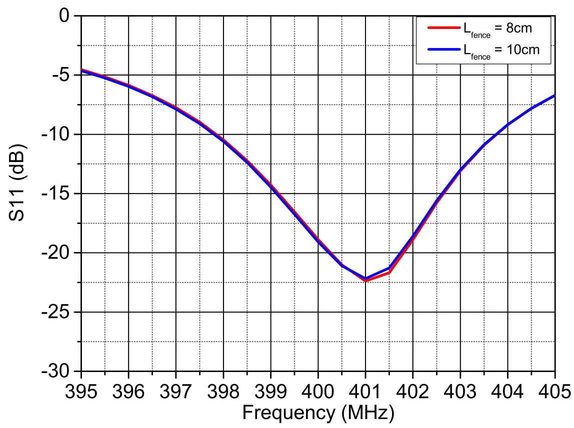

Fig. 20. Reflection coefficient as a function of the frequency for the metallic fence model.

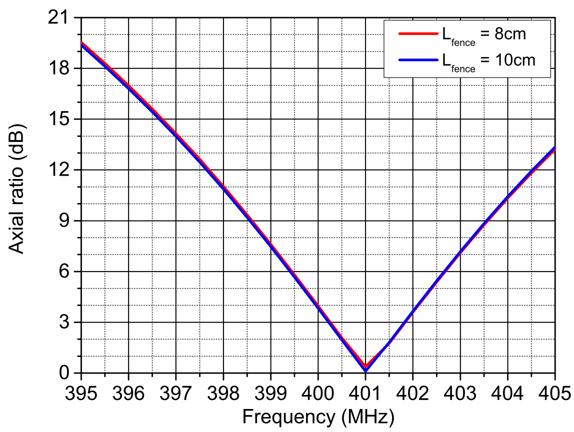

Fig. 21. Axial ratio as a function of the frequency for the metallic fence model, for $\theta = \phi = 0^\circ$.

The radiation pattern for the antennas considering the metallic fence with 8 cm and 10 cm are shown in Figures 22 and 23. The maximum gain for $L_{fence} = 8$ cm was 4.63 dBi and for $L_{fence} = 10$ cm was 4.79 dBi. As it can be observed, the maximum gain for these models increased when compared to the topologies presented previously. The front-to-back ratio values for $L_{fence} = 8$ cm and 10 cm were 8.32 dB and 10.03 dB, respectively.

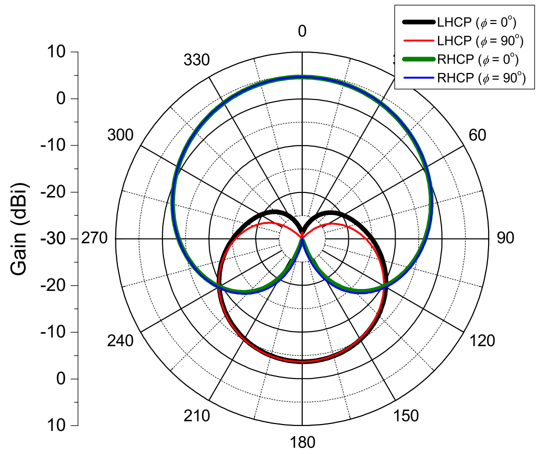

Fig. 22. Gain for the antenna with metallic fence with length of 8 cm.

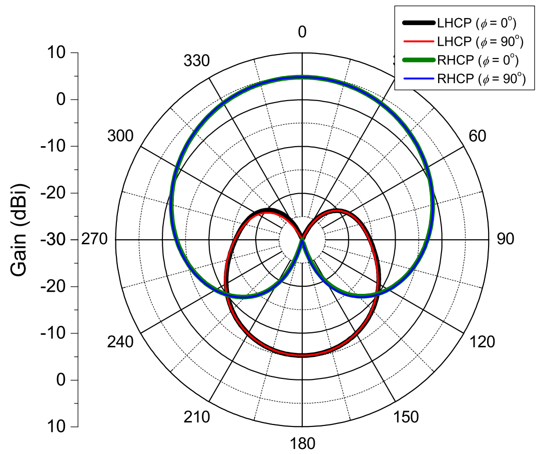

Fig. 23. Gain for the antenna with metallic fence with length of 10 cm.

V. Antenna Array Design with Extended GND using Metallic Fence

In section IV, three single antenna models considering a ground plane extension have been designed and described. The best performance was obtained considering extensions with metallic fences. In order to increase the gain of the uplink antenna, an array composed of four antennas can be employed. The structure of the array installed onto the nanosatellite is shown in Figure 24. In this geometry, the antennas are spatially rotated by 90° from each other. In order to generate circular polarization, the patches must be excited with 90° progressive phase shift [15]. Otherwise, the radiated field would be cancelled out in the boresight. Considering this procedure, the resulting radiation pattern for the model with $L_{fence} = 8$ cm is shown in Figure 25.

To investigate the antenna performance under the influence of the fence size, a simulation for $L_{fence} = 10$ cm was also carried out. The resulting gain pattern is shown in Figure 26.

The results of active reflection coefficient and axial ratio for both investigated values of L_{fence} are presented in Figures 27 and 28, respectively. The gain using metallic fence with 8 cm

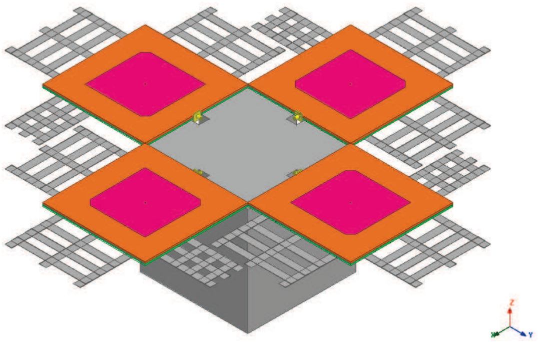

Fig. 24. Antenna array with metallic fences installed onto the nano-satellite.

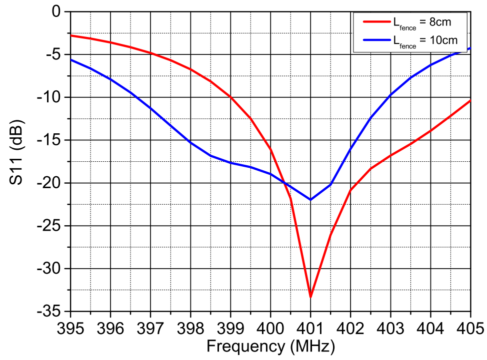

Fig. 27. Active reflection coefficient as a function of the frequency for the antenna array with metallic fence model.

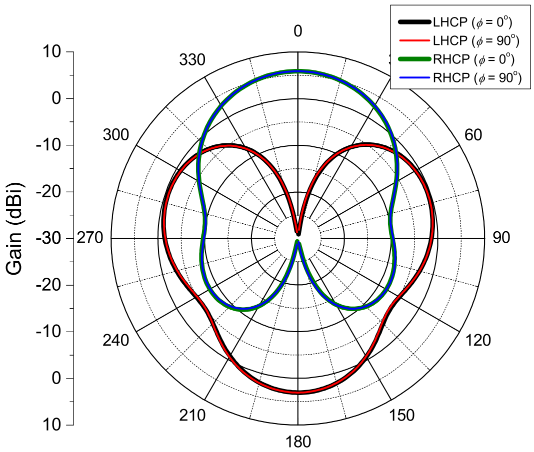

Fig. 25. Gain pattern for the antenna array with metallic fences and length of 8 cm.

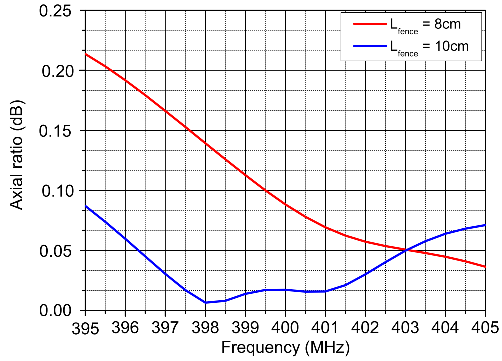

Fig. 28. Axial ratio as a function of the frequency for the antenna array with metallic fence model.

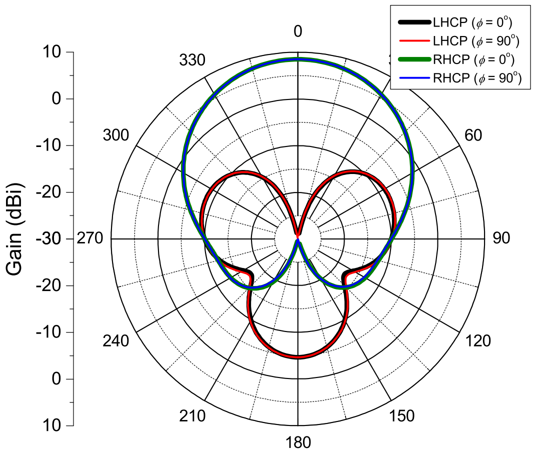

Fig. 26. Gain for the antenna array with metallic fences with length of 10 cm.

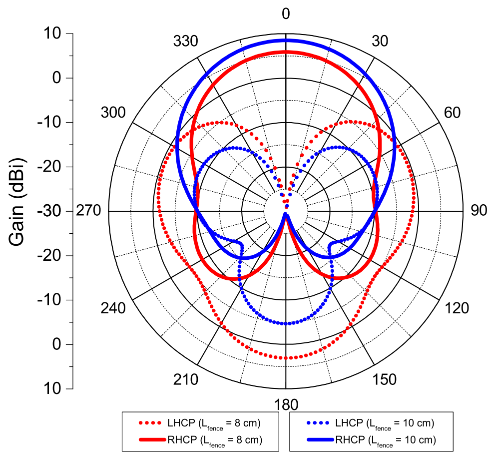

Fig. 29. Gain for the antenna array with metallic fences considering $L_{fence} = 8$ cm and $L_{fence} = 10$ cm.

was of 5.83 dBi and for 10 cm was of 8.46 dBi. As it can be observed, an increase of 2.6 dBi was obtained. This improvement can be better seen when both traces are in the same plot, as shown in Figure 29.

VI. Conclusion

This paper presented the design of circularly polarized microstrip antennas for meteorological nano-satellites. The main goal was to increase the gain in the boresight by increasing the front-to-back ratio. This has been achieved by extending the ground plane using metallic cylindrical rods or strips. The front-to-back ratio and the gain of the standard antenna operating at 401 MHz and with GND dimensions of

19×19 cm was 3.82 dB and 1.73 dBi, respectively. By adding metallic fences to each antenna edge, these parameters have been increased respectively to 10.04 dB and 4.79 dBi. This represents a great improvement in the antenna performance with little increase in the antenna volume and weight. All the requirements in terms of bandwidth, polarization and axial ratio have been fulfilled. Finally, it has been demonstrated that the GND extension technique can be used to compose an antenna array onto the nano-sat, whereby a gain of 8.32 dBi has been achieved.

VII. Acknowledgements

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