Microstrip Antenna with Extended Ground Plane for Meteorological Nano-Satellites

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***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 and to optimize the decoupling between the main and the cross polarizations, metallic strips were attached to the antenna ground plane. The antenna 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.**

***Keywords*— Microstrip antenna, Antenna array, Meteorological Nano-Satellite, Circular polarization.**

I. INTRODUCTION

The CONASAT program was created by the National Institute for Space Research (INPE), considering the 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 data collected by the data collecting platforms (PCDs) installed in remote areas of Brazil, where wireless communication is not possible. The dimension 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 10 cm of edge size and a maximum mass of 10 kg). 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 [1].

The microstrip antenna array structure has some advantages, such as low cost for mass production, light weight, compactness and design flexibility [2]. In the literature, can be find some techniques to design microstrip antennas for nano-satellites. The authors of [3] suggest a microstrip antenna model that operates in S-band for applications such as telemetry and high speed data transmission. In [4], the design of antennas with triangular patches for hexagonal shaped nano-satellites is performed. In [5] and [6], an analysis of radiation characteristics of low-cost and circularly polarized microstrip antennas is presented. Further geometries of microstrip antennas for circular polarization are presented in [8]-[9].

The analysis of antenna arrays for nano-satellites using Thermoset Microwave Materials (TMM) with different dielectric constants has been reported in [7]. The proposed array was designed to operate in receiving mode (uplink) at 401 MHz.

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Due to the small electrical dimensions of the nano-sat, the radiation pattern presents low front-to-back ratio. 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 ground plane. The antennas were designed and analyzed through electromagnetic simulations in the Ansys HFSS software [10]. 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 their 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, in order to increase the effective ground plane. Finally, section V present 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.

The following specifications apply for the UHF antenna: right hand circular polarization with axial ratio lower than 6 dB, input impedance matched to 50 Ω and bandwidth of 5 MHz. The antenna dimensions must be smaller than 20 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 small electrical size. For this case, in order to reduce the patch, the use of dielectric substrates with high dielectric constants is recommended [11].

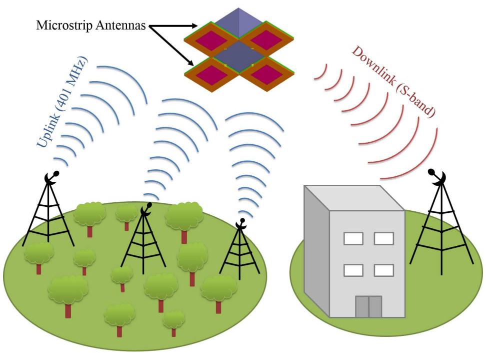

Fig. 1. Scenario for the meteorological nano-satellite.

III. Standard Antenna Design

Circular polarization can be obtained with the use of a corners-truncated patch [2], [12]. In order to achieve the desired bandwidth, the substrate used is thick and the antenna is fed with a microstirp line with electromagnetic coupling. The microwave laminate used is Taconic CER-10 [13], which has dielectric constant of $\varepsilon_r = 10.2$ and thickness of 3.18 mm. In order to obtain the desired bandwidth, two of such layers have been employed between the feed line and the ground plane (GND) and two layers between the line and the square patch with corner-truncated. All the layers are glued with the prepeg Fast Rise 27 (FR27) [14], which has dielectric constant of $\varepsilon_r = 2.75$ and thickness of 0.0762 mm. The cross-section view of the structure described is presented in Figure 2. As shown in the 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. After the optimization of axial ratio and impedance matching, the following dimensions were obtained: $W = 11.67$ cm, $L = 5.54$ cm, $W_{Z0} = 0.35$ cm and $A = 0.70$ cm. The results for axial ratio, reflection coefficient and radiation pattern are shown in Figures 4 - 6, respectively. The maximum gain obtained for this antenna was of 2.03 dBi.

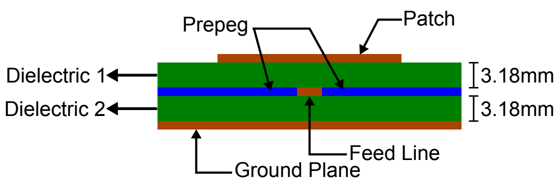

Fig. 2. Cross-sectional view of the designed antenna.

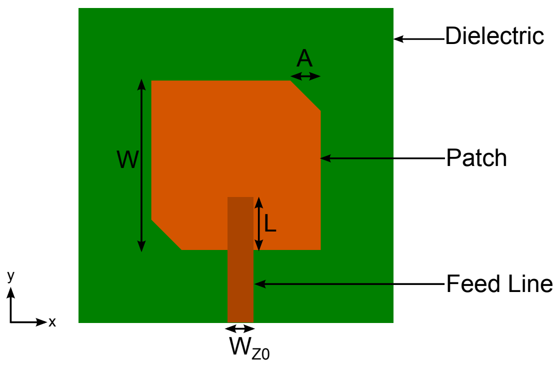

Fig. 3. Top view of the designed antenna.

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 nanosatellite, 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 6 exhibits large back radiation. Due to this characteristic, the antenna gain is much lower than it is normally expected for a microstrip antenna, since large amount of power in comparison to the

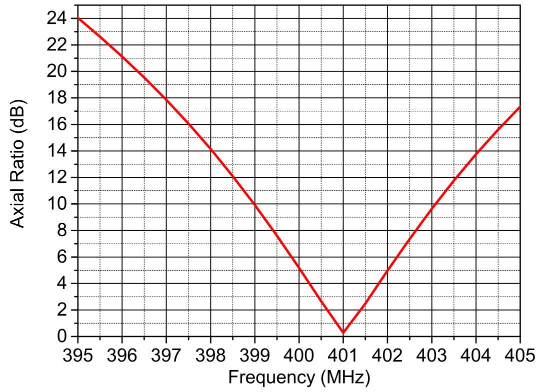

Fig. 4. Axial ratio as a function of the frequency for the single antenna, in $\theta = \phi = 0°$.

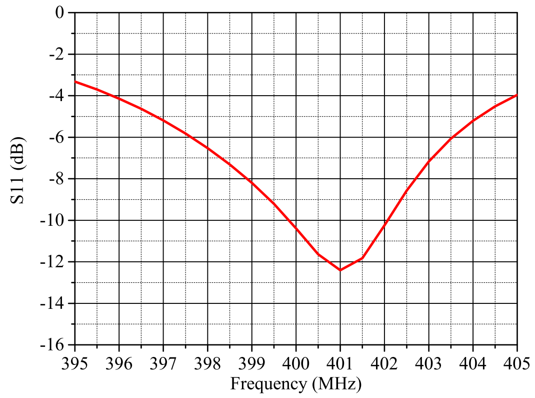

Fig. 5. Reflection coefficient as a function of the frequency for the single antenna.

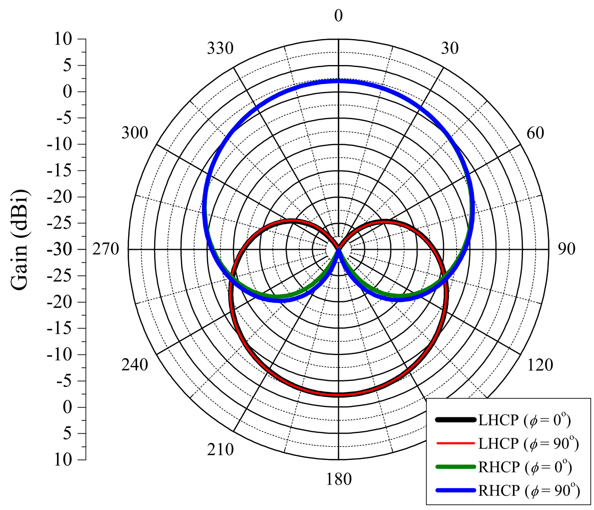

Fig. 6. Gain pattern for the single antenna.

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-sattelite is launched. Two types of metallic structures have been considered: cylindrical rods and metallic strips.

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 7, where rods have been attached to each GND edge. In order to assess the number and lenght of the rods that should be used to obtain acceptable results, the following cases have been simulated: 2 or 4 rods attached to each antenna edge with lengths of 4 cm, 6 cm and 8 cm.

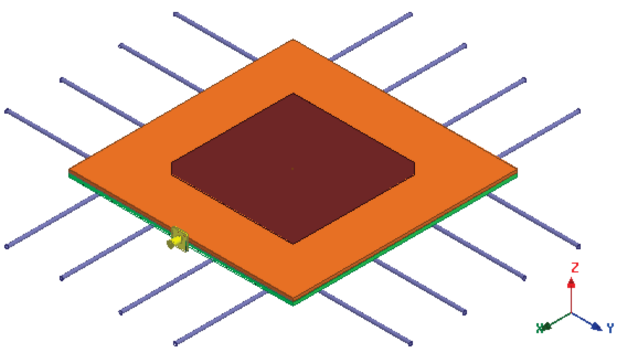

Fig. 7. Structure of the designed antenna with cylindrical rods.

The presence of the metallic rods shifted the operating frequency of the antenna. After the new optimization of the antenna dimensions, the reflection coefficient and axial ratio were plotted and are shown in Figures 8 and 9. Also, the gain patterns were computed and the best results are shown in Figures 10 and 11 for two and four rods in each side of the antenna, respectively. The gain achieved for each case is presented in the Table I. The best performance in terms of gain has been obtained for four 8-cm long rods attached to each GND edge. All the specifications have been fulfilled with this structure.

TABLE I

MAXIMUM GAIN FOR ALL LENGHT AND NUMBER OF CYLINDRICAL RODS.

Lenght	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

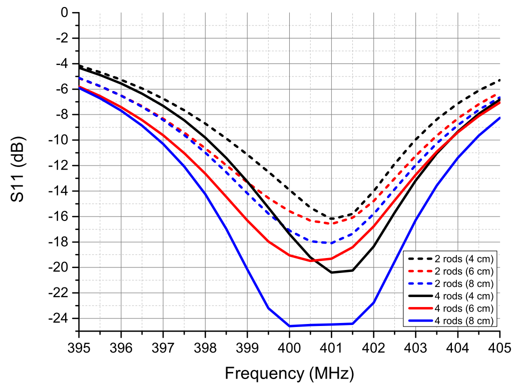

Fig. 8. Reflection coefficient as a function of the frequency for all cases employing cylindrical rods.

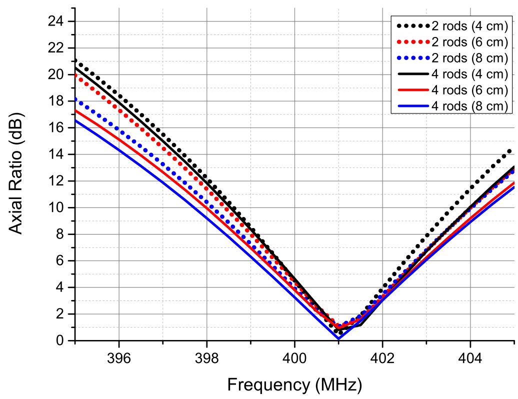

Fig. 9. Axial ratio as a function of the frequency for all cases employing cylindrical rods.

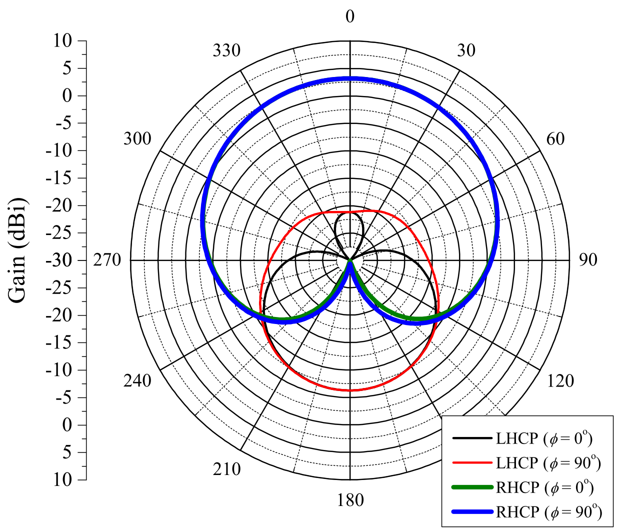

Fig. 10. Gain patterns for the antenna with two 8-cm cylindrical rods attached to each GND edge.

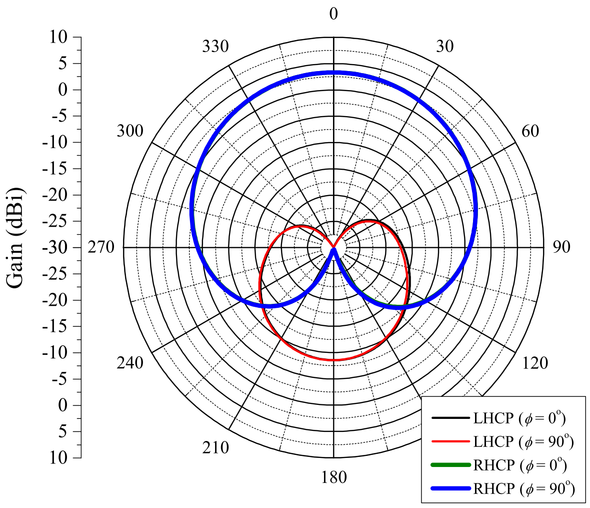

Fig. 11. Gain patterns for the antenna with four 8-cm cylindrical rods attached to each GND edge.

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 used. This demands the use of machines to open every rod. 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 very first minutes after the satellite is launched. Moreover, it results in the increase of the total weight of the nano-satellite, which, along with the former disadvantages, is unacceptable.

An alternative approach would be 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 can be automatically opened when the antenna is deployed, hence saving space and weight.

The extended GND with metallic strips is sketched in Figure 12. 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 antenna and their length was tested for 4 cm, 6 cm and 8 cm.

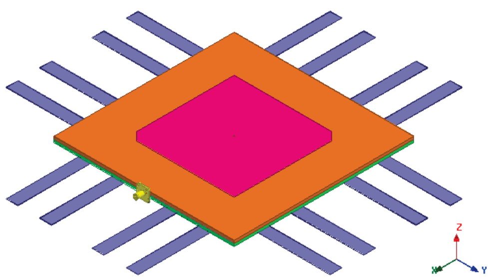

Fig. 12. Structure of the designed antenna with rectangular rods.

After a new optimization of the antenna dimensions and the attachment of the strips, the resulting reflection coefficient and axial ratio are shown in Figures 13 and 14. The gain patterns for the best cases are shown in Figures 15 and 16 for two and four rods 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. For this configuration, all the specifications have also been fulfilled.

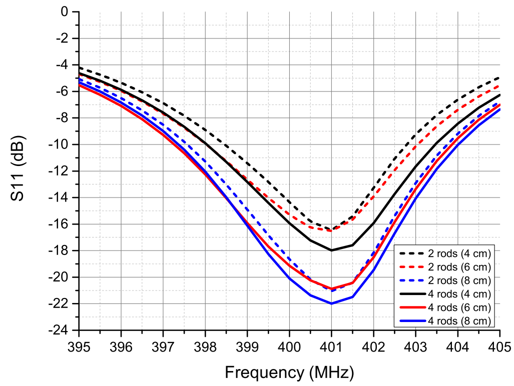

Fig. 13. Reflection coefficient as a function of the frequency for all cases of the rectangular rods.

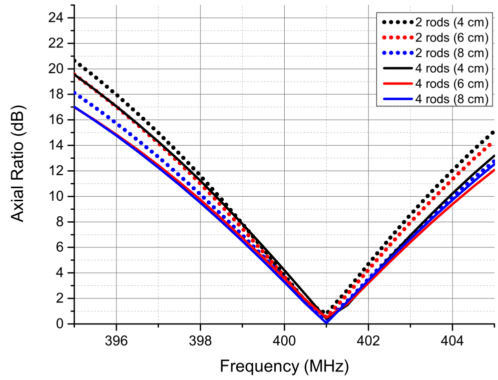

Fig. 14. Axial ratio as a function of the frequency for all cases of the rectangular rods.

TABLE II
MAXIMUM GAIN FOR ALL LENGHT AND NUMBER OF RECTANGULAR RODS.

Lenght	Number	
	2 Rods	4 Rods
4 cm	2.64 dBi	3.12 dBi
6 cm	2.97 dBi	3.29 dBi
8 cm	3.18 dBi	3.32 dBi

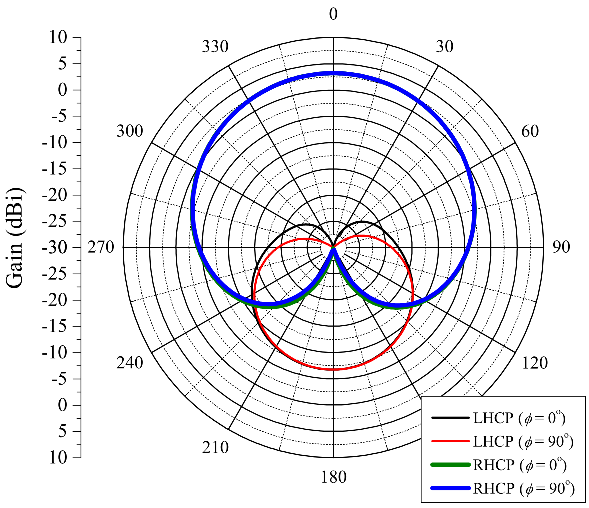

Fig. 15. Gain for the antenna with two rectangular rods and lenght of 8 cm.

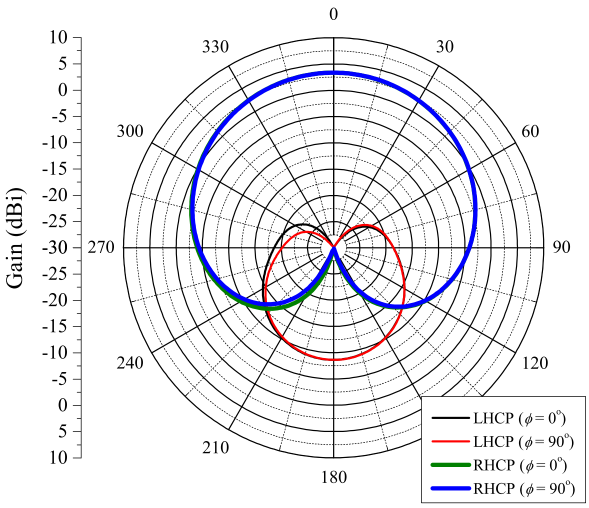

Fig. 16. Gain for the antenna with four rectangular rods and lenght of 8 cm.

V. 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 5.0 dB and 2.0 dBi, respectively. By adding 4 metallic strips to each antenna edge, these parameters have been increased respectively to 12.0 dB and 3.32 dBi. This represents a great improvement in the antenna performance with little increase in the antenna volume and weight. Finally, all the requirements in terms of bandwidth, polarization and axial ratio have been fulfilled.

VI. Acknowledgements

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