A Microstrip Antenna for Meteorological Nano-Satellites for UHF Uplink

Edmilson C. Moreira, Antônio S. B. Sombra, João C. M. Mota, Marcos V. T. Heckler and Marcelo P. Magalhães

***Abstract*— A truncated microstrip square patch antenna is proposed and designed in this paper. Such device is used for UHF Wireless Uplink by CubeSat nano-satellite. The antenna is composed of one truncated square patch, a "L" shaped $\lambda/4$ transformer and a extended ground plane. Simulation results of this RF device are presented and discussed.**

***Keywords*— Antennas, nano-satellite, Communication Systems.**

I. INTRODUCTION

Microstrip patch antennas are used in various wireless applications, being present in missiles, aircrafts, spacecrafts and satellites, as stated in [1], for example. These, according to [1] and [2], are lightweight, thin, cheap, easy to manufacture and to polarize circularly and linearly. Microstrip patch antennas are easily integrated with feeding networks and impedance matching devices.

One characteristic of printed antennas is that the antenna dimensions are dependent on the dielectric constants of the employed microwave laminates. In many situations, miniaturized radiators can be obtained by using substrates with high dielectric constant. Although, it is well known that these features have the disadvantage of surface waves excitation , which can degrade the radiation efficiency of the antenna and deteriorate the shape of the radiation pattern and the polarization. Additionally, another limitation of common microstrip antennas is its narrow operation band, which tends to be reduced even further if the dielectric constant is increased.

Microstrip antennas have been used already in several nano-satellites. One interesting approach is presented in [3], [4], where the design and analysis of printed quasi-Yagi antennas for WLAN and Wi-Fi applications are shown. In [5], [6], a method for the construction of microstrip antennas applied to communication systems in the S-band is presented. A study of the influence of new nano-composite materials on the performance of antennas is discussed in [7]. In [8], the design of a microstrip antenna with multiple layer substrates is presented.

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In this paper, the design of microstrip antenna for meteorological nano-satellites is presented. Since the nano-satellite presents a cubical shape with edges no larger than 20 cm, the main challenge is to design microstrip antennas that are small enough to operate at 401 MHz and still exhibit good performance. Section II shows the functional and the non functional requirements of the antenna. In Section III, the entire antenna conception phase is described. Section IV shows the simulation results of the conceived antenna and present work is proposed.

II. THE ANTENNA REQUIREMENTS

As explained, the antenna will be carried by a 20cm x 20cm x 20cm CubeSat 2U nano-satellite [9] and will serve as data relay for transmission of meteorological data collected by stations deployed in remote areas in the rain forest, for instance, and operate at 401MHz. whereby no wired communication is possible. This scenario is showed in Fig. 1

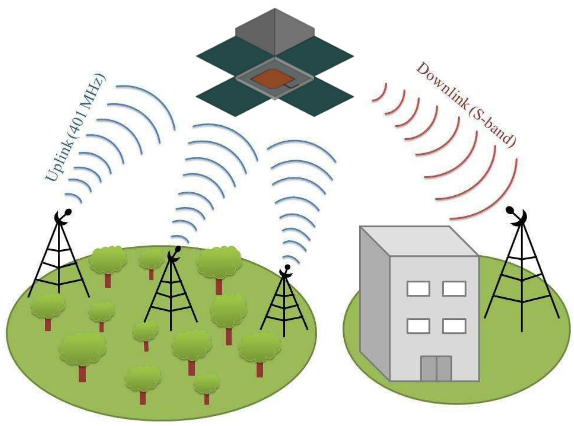

Fig. 1: Transmission system.

According to [10], this scenario implicates that the antenna presents a minimum impedance bandwidth of 5MHz centered around 401MHz, no less than 5dBi of gain and a 6dBi maximum value for Axial Ratio in 401MHz. Mainly, the antenna will use the area provided by one face of CubeSat, being it a square of 400cm^2. Although, a simplistic analysis using classic design formulas [1] shows that the is extremely challenging he achievement of those functional characteristics using only 400cm^2 of square area. In [10], simulations results of microstrip antennas designed using only 400cm^2 shows a maximum gain of 2.74dBi, attesting the difficulty cited. The CubeSat external lateral faces are frequently used host solar panels and other communication systems according with

[11]. The use of those faces increases the area available for antenna design to 2000cm^2, making the development of this antenna feasible. Finally, the antenna must be feed by a 50Ω transmission line.

III. The Antenna Conception

This phase begins with the definition of the dielectric substrate and the conductor of the antenna. Even with the possibility of use the external lateral faces, the microstrip patch and the impedance matching must be contained in the bottom face of the nano-satellite. According to [12], dielectric substrates of TMM6, ϵ_r=6.0, and TMM10i, ϵ_r=9.8, laminates allows the conception of the antenna in question with square patch with lateral dimension smaller than 20 cm. The use of TMM10i as dielectric substrate permits a deeper miniaturization of the antenna, in comparison with TMM6, with no relevant decrease in electromagnetic performance, providing more area for the impedance matching device design. Therefore, the antenna will be projected using TMM10i laminates. The antenna's electric conductor will be the copper present in the TMM10i laminates and standard steel for the external lateral faces.

Now, that the antenna's dielectric substrate and the conductor are defined, is time to focus in electromagnetic engineering of the antenna. As stated in [1], the square patch, is the most easy to fabricate and analyze, and can be used from the simplest to the most demanding applications. Circular and Elliptical polarization in square patches can be easily achieved using truncated corners [13]. A impedance matching network influence directly the overall efficiency and bandwidth. The inset feed and the $\lambda/4$ transformer are one of the simplest to design and to fabricate feeding technique and impedance matching device, respectively. According with [14], ground plane extension could be used as gain improvement technique regarding ground planes with small area($< \lambda_0^2$). Thus, the antenna is specified as circular polarized truncated square microstrip patch with a extended ground plane. The truncated corner square patch is connected to feeding transmission line thru a “L” shaped $\lambda/4$ transformer, being both supported by a layer of TMM10i laminate dielectric substrate. The ground plane is composed by the bottom and four external faces. The patch, the impedance matching network and the dielectric substrate are mounted directly over the bottom external face. The external lateral faces open after the satellite is dropped off the launching vehicle, setting up the final antenna configuration. The truncated square patch side length is represented by Lp. The “L” shaped $\lambda/4$ transformer width is given by Wt and the length of both “arms” of this device are presented by Lt_1 e Lt_2. The dielectric substrate layer with Hm of height has the same side length of any CubeSat external face: Lg.

Now, that the basic model of the antenna is conceived, its exactly dimensions must be determined in order to operate as needed. Initially, the physical and mathematical tools showed in [15], [16], [13] and [1], allowed the specification of these preliminary antenna dimensions. Then, a virtual model based on the proposed antenna configuration with their preliminary dimensions is designed into a CAD simulation software that uses the finite element method called Ansoft HFSS^{TM}. With this virtual model, several parametric studies were conducted based on analysis using the cavity and transmission line models and a systematic design method presented in [17]. These studies resulted in a final optimized antenna virtual model, based on the proposed configuration that works as centered around 401MHz. Fig. 2 shows the refined model of the antenna.

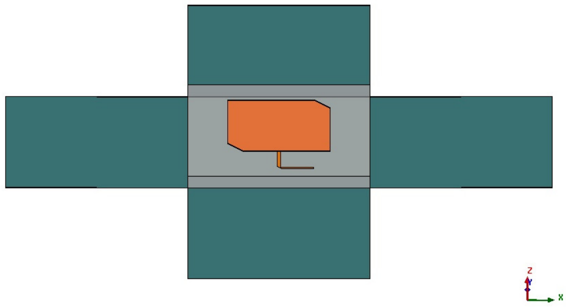

Fig. 2: Proposed antenna configuration.

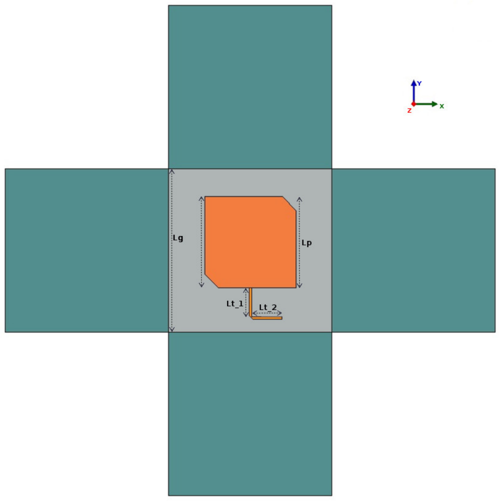

Fig. 3: Final antenna model.

The table I illustrates the antennas most relevant dimensions of this final model.

TABELA I: *Important antenna parameters.*

Parameter	Lg	Lp	Lt_1	Lt_2	Hm
Length(mm)	200	112	35	37,5	15

IV. Results

The truncated microstrip square patch in question is validated by the simulated obtained results of reflection coefficient, impedance, axial ratio and gain . The simulation, as mentioned earlier, was made with Ansoft's HFSS^{TM}. Fig. 4 shows the reflection coefficient of simulated antenna. The simulation results shows minimum value of -19.7517dB at 400.9MHz.

The impedance bandwidth, which includes values less than -10dB, as [18], is 5.3MHz and is located between 398.67MHz and 403.9MHz.

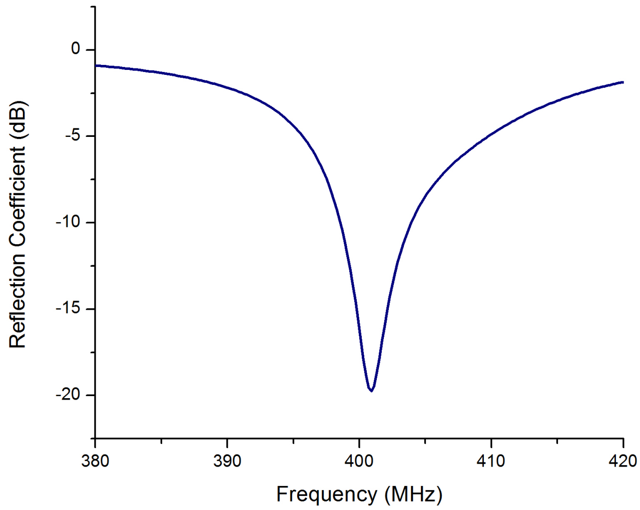

Fig. 4: Reflection Coefficent.

Figs. 5 and 6 shows the simulated values of real and imaginary impedance parts, $Re[Z]$ and $Im[Z]$, respectively. Those values justify the good results of return loss, since, at 401 MHz, the antenna has simulated real impedance of 41.7Ω that is really close to 50Ω present in the feed line.

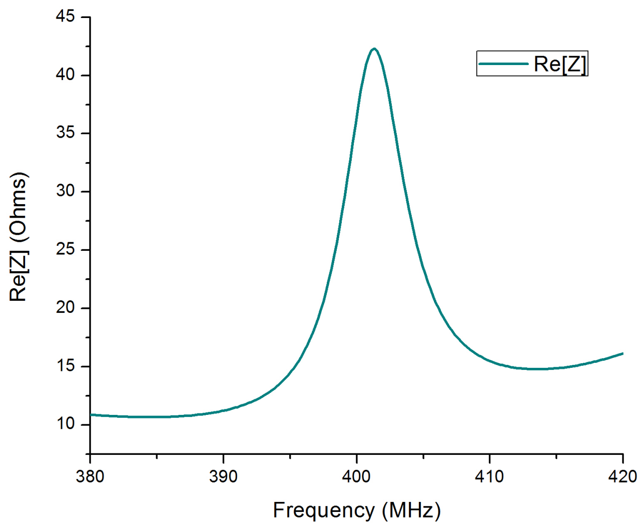

Fig. 5: Real part of the impedance.

The antenna's Smith Chart, illustrated in Fig. 7, compile those impedance informations in Figs. 5 and 6 together. A very small loop can be seen close to the center of the Smith Chart indicating that two resonant, orthogonal and *quasi*-degenerate modes are excited at close frequencies, according to [19], making possible CP/EP radiation.

The theoretical radiation pattern of the studied antenna when $\phi = 0$ is presented in Fig. 8. Operating 401MHz, the device presented a maximum gain of 4.21dBi. Therefore, the results presented Fig. 8 confirm that this works antenna has good gain, being it greater than specified in requirements.

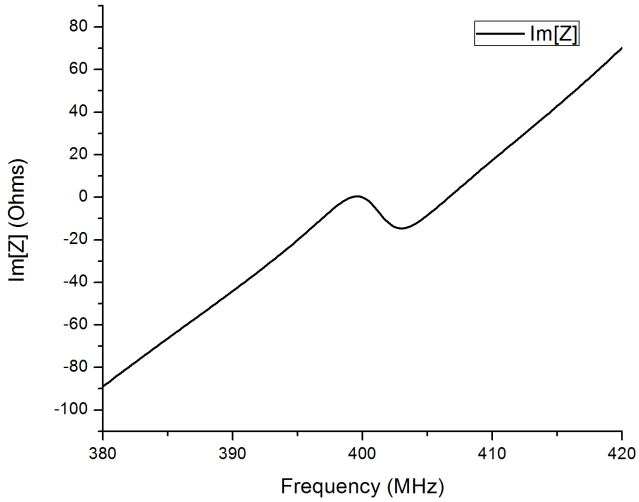

Fig. 6: Imaginary part of the impedance.

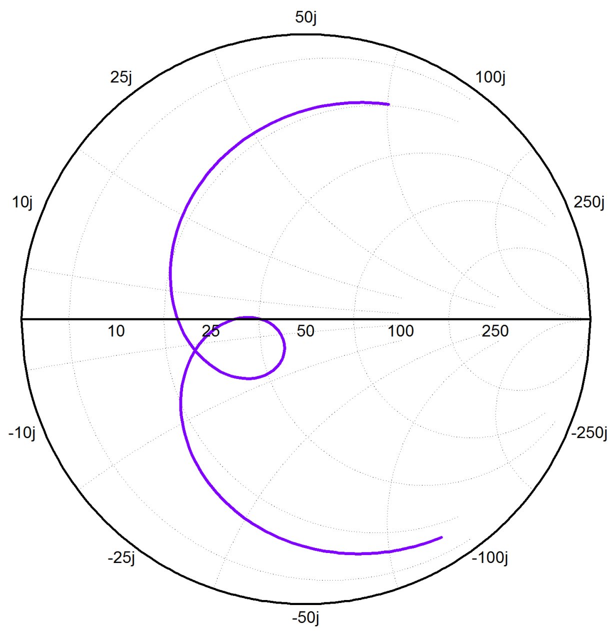

Fig. 7: Input impedance Smith Chart.

The simulated values of axial ratio versus frequency can be seen in Fig. 9. In it, is possible to observe that the minimum axial ratio value is of 4.9dB at 401MHz, fulfilling antenna's polarization requirement.

The theoretical radiation pattern in three dimensions is shown in Fig. 10 and completes the characterization of the antenna patch. One important thing that can be concluded just by observing this Fig.10 is that the radiation pattern is quite symmetrical around the z axis.

V. Conclusion and Future Work

This work expresses the idealization, design, simulation of a truncated microstrip square patch antenna for Meteorological Nano-Satellites that uses 401MHz for Uplink communication. The equipment confirmed its functionality as an electromagnetic radiator in the above-mentioned frequency, with gain

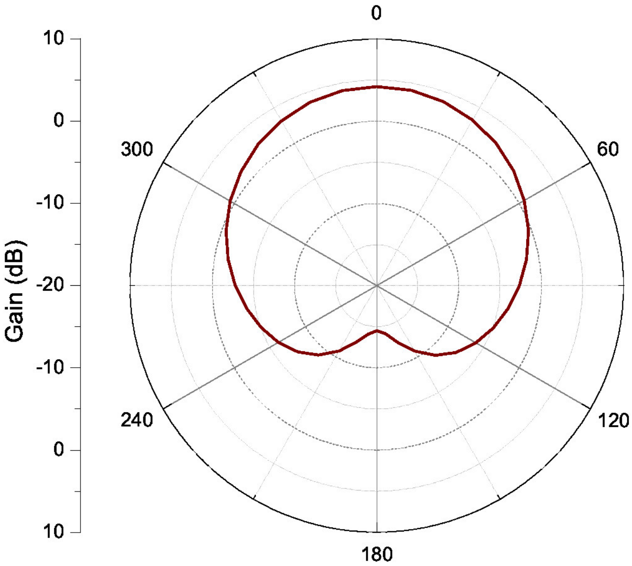

Fig. 8: Radiation pattern.

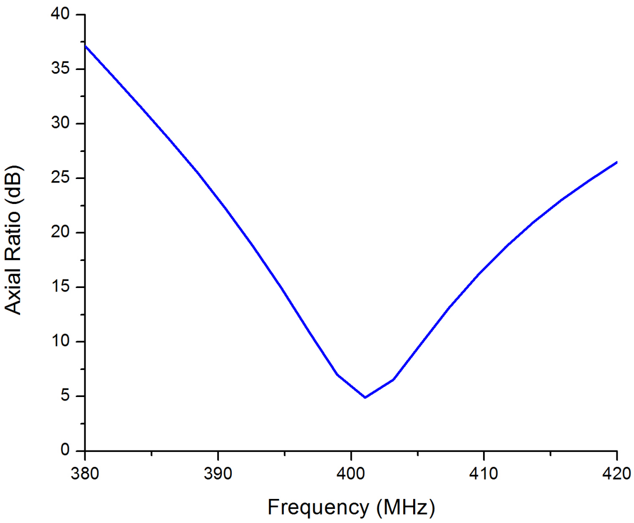

Fig. 9: Axial ratio.

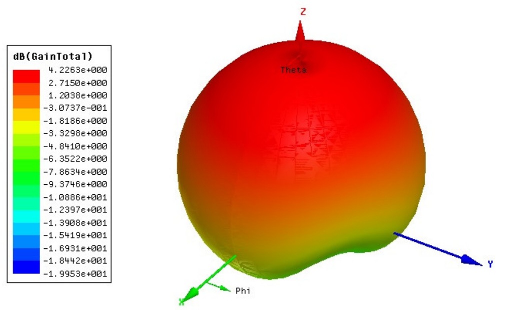

Fig. 10: 3D radiation pattern.

higher than 4dBi and an axial ratio of less than 6dB at 401MHz. As future work, is mandatory that a prototype be manufactured, allowing the collection of experimental data that will be crossed with the simulated results presented in this work.

VI. ACKNOWLEDGEMENT

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