Telemetry X-band Antenna Payload for Nano-satellites

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***Abstract*— This paper presents a compact X-band antenna with an isoflux radiation pattern and circular polarization. It consists of a miniaturized helix antenna connected to a stripline circuit that provides a sequential rotation feeding. The antenna is arranged over a vertically corrugated ground plane and it has been optimized for a CubeSat 3U nano-satellite platform. Its design, manufacture and results are here presented.**

***Index Terms*—antenna, X-band, nano-satellite, TT&C.**

I. INTRODUCTION

This study has been accomplished within the framework of a Research and Technology (R&T) program of the Centre National d'Études Spatiales (CNES). The aim of the study is to explore different designs for a compact X-band antenna with an isoflux pattern and Right Hand Circular Polarization (RHCP). The antenna is meant to be compatible with a nano-satellite platform of type CubeSat 3U consisting of a parallelepiped structure of 10 cm x 10 cm x 30 cm. The proposed antenna solution has to be then capable to carry the data rates of the eventual Telemetry, Tracking and Command (TT&C) subsystem implemented in the CubeSat platform. The antenna is to be arranged on top of the face of the nano-satellite that looks to the Earth. An artistic representation of this arrangement can be seen in Fig. 1.

CNES has selected two partners for this R&T study in order to evaluate different antenna configurations. MVG Industries (France) has explored solutions with antennas of reduced diameter that use the perpendicular dimension of the satellite plane to generate the desired radiation pattern (e.g. helix antennas). The Xlim laboratory, attached to the University of Limoges (France), has evaluated solutions with lower profile antennas using the satellite plane to generate the isoflux pattern (e.g. array antennas). An overview of this combined study can be found in [1]. This paper summarizes the tasks accomplished by MVG Industries.

Most of the antenna designs currently used to generate isoflux patterns with circular polarization are based in helix and corrugated horn architectures [2, 3]. However, these antennas are not usually compatible with nano-satellite platforms as they are too bulky for its reduced dimensions. This limitation in volume leads to the research of alternative antenna solutions, smaller and better integrated in the platform.

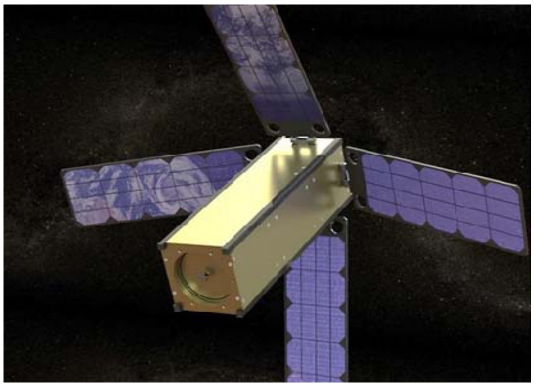

Fig. 1: Artistic representation of the CubeSat 3U platform

II. ANTENNA SPECIFICATION REQUIREMENTS

The reduced size of the CubeSat 3U platform imposes an important constraint in terms of the available volume for the antenna. This results in a maximum antenna size limited by a parallelepiped of 9 cm x 9 cm x 2 cm. The antenna can be partially inserted inside the platform so that it that does not surpasses the top face of the nano-satellite more than 0.9 cm in the vertical axis.

The antenna must provide an isoflux radiation pattern in RHCP polarization between 8 GHz and 8.4 GHz. In order to achieve this kind of pattern the gain at ±60° in elevation should be 3 dB higher than at boresight. A detailed overview of the specifications is shown in Table I.

TABLE I. ANTENNA SPECIFICATIONS

Parameters	Specifications
Bandwidth	8.0 - 8.4 GHz (5%)
Reflection Coefficient	VSWR < 1.2:1 (S_{11} < -20.8 dB)
Polarization	RHCP
Gain	> 0 dB within a cone of ±65° (required) > +3 dB at ±60° compared to boresight gain (objective)
Axial Ratio	< 3 dB within a cone of ± 65°
Volume	Parallelepiped of 9 cm x 9 cm x 2 cm Max. vertical oversize of 0.9 cm
Connectors	SMA female

III. CANDIDATE ANTENNA TOPOLOGIES

MVG Industries performed an initial state of the art study to identify potential antenna solutions and compare their performance through a simulation trade-off. Helix type antennas were considered focusing on quadrifilar designs in both cylindrical and conical shapes. These models eventually evolved to a miniaturized architecture that combines two cross dipoles connected to a cylindrical helix section (Fig. 2), which was finally selected as the most promising candidate. Alternative solutions such as a stacked patches structure or a primary source surrounded by cavities were also studied. Other proposals found in literature, such as the combination of a biconical antenna and a horn [4], were taken into account as well. The selected candidate was chosen not only due to its electrical performance but also considering its mechanical implementation and the volume available in the CubeSat platform.

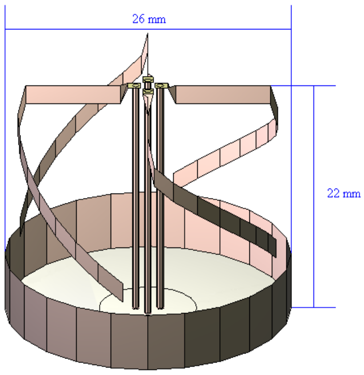

Fig. 2: Miniaturized quadrifilar wire helix antenna

IV. PROPOSED ANTENNA TOPOLOGY

A. Antenna architecture

The antenna concept selected in the trade-off phase was taken as a starting point to develop a more refined design which led to a final architecture definition. The resulting antenna consists of a miniaturized helix topology composed by four pairs of folded strands arranged in a cylindrical disposition. The use of eight strands in total improves the radiation symmetry in azimuth. The four pairs of folded strands are fed in phase quadrature by four bars so that a circular polarization is obtained. The thickness of the strands and feeding bars is 1 mm. The shape of the bended strands allows either a right or left circular polarization. The radiating element is situated over a circular ground plane of 80 mm in diameter that includes a vertical corrugation along its perimeter. This corrugation avoids the propagation of undesired currents across the structure of the nano-satellite. The exciting bars are connected to a printed feeding circuit located below the ground plane. A small cylinder at the base of the four excitation bars helps to improve the axial ratio for elevation angles within ±65°. The antenna architecture has a total thickness of 21.5 mm and is depicted in Fig. 3. It is partially inserted inside the CubeSat so that the strands exceed the top face of the platform by only 9 mm, in agreement with the specifications.

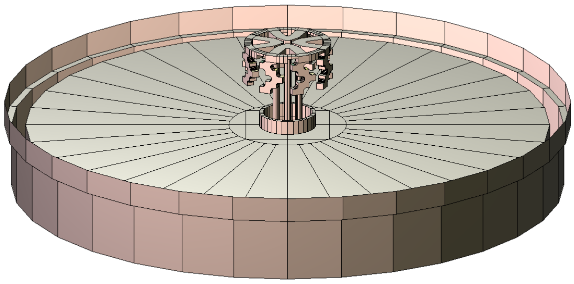

Fig. 3: Proposed antenna architecture

B. Feeding circuit

The feeding circuit is designed in triplate technology using two substrates “Rogers 3003” of 1.524 mm thickness each one. The excitation in quadrature phase is accomplished with two branch-line couplers connected to a T-junction. One of the sections of the T-junction has a 180° phase shift with regard to the other one. This type of architecture provides a RHCP polarization as each bar is excited with a 90° phase difference at the output ports of the couplers. The isolated ports of the branch-line couplers are matched with 50 Ω loads to absorb any residual reflections. A matching stub is added just before each transition to the four excitation bars of the antenna. These bars are soldered to the circuit through four metalized holes. The diameter of the circuit is 64 mm so that it can be placed below the antenna ground plane without intersecting its vertical corrugation. A complete layout of the feeding circuit can be seen in Fig. 4.

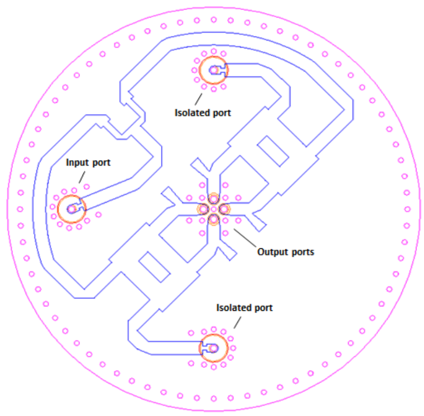

Fig. 4: Antenna feeding circuit

C. Simulated performances

The radiating element and its feeding circuit have been evaluated by using the electromagnetic solver IE3D. The circuit shows an insertion loss of 0.3 dB. The maximum deviation seen at its output ports with regard to the ideal values to obtain the RHCP polarization are 0.15 dB in magnitude and 4.5° in phase, at the bandwidth edges. The simulation of the complete antenna structure shows that the reflection coefficient, gain and axial ratio remain within the specifications. The isoflux angle is obtained at ±35° in elevation instead of the desired ±60° initially demanded. This is due to the reduced size of the antenna necessary to comply with the volume constraints. The radiation pattern of the antenna can be seen in Fig. 5 at the central frequency of 8.2 GHz for several cuts in azimuth (please note that it shows directivity values).

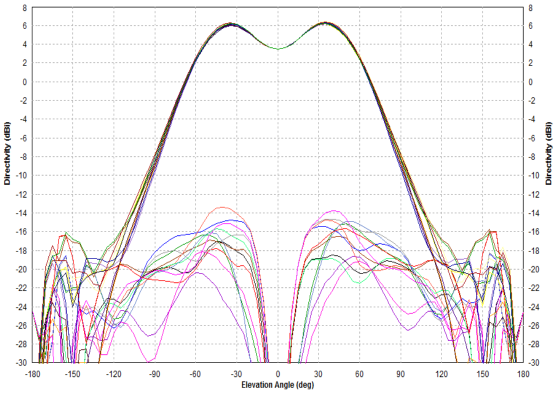

Fig. 5: Simulated radiation pattern (8.2 GHz)

V. Prototyping

At this stage of the study no constraints regarding space qualification are required, so the antenna can be considered as an Engineering Model (EM) prototype. Nevertheless, a special attention has been given to the chosen materials and procedures in order to minimize the risks for an eventual Engineering and Qualification Model (EQM).

A. CubeSat 3U mockup

The CubeSat 3U platform is manufactured in an anodized aluminum structure depicted in Fig. 6. The antenna including its corrugated ground plane and feeding circuit is integrated into the top face by means of screws.

Fig. 6: Manufactured CubeSat 3U platform with antenna on top

B. Antenna prototype

The antenna prototyping has been accomplished in different steps. The feeding circuit is manufactured by using printed circuit technology. Concerning the radiating element, the folded strands structure is obtained after a milling process. The metallic bars are manufactured separately and soldered to the strand structure and then to the feeding circuit. A detailed view of the radiating element is shown in Fig. 7.

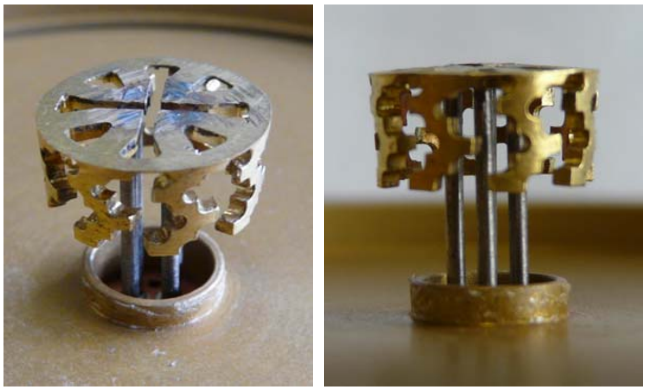

Fig. 7: Manufactured radiating element

VI. Measurement Results

The antenna has been integrated on top of the Cubesat platform and measured in S-parameters and radiation patterns. The radiation measurements have been performed in the near field measurement facility SG-64 of MVG Industries (Fig. 8). A general acceptable antenna performance is obtained but degraded compared to the simulations. This is probably caused by some mechanical asymmetries of the radiating element given the fact that its assembly is quite delicate.

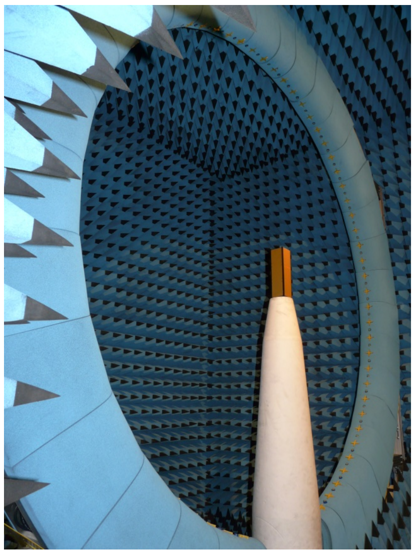

Fig. 8: Measurement of the antenna in the SG-64 facility

The isoflux pattern is obtained as expected at ±35° in elevation, with a gain close to 0 dB at boresight. The axial ratio at central frequency remains below 4 dB within ±65°, but it is further degraded at the ends of the bandwidth. The gain radiation pattern for several azimuth cuts at the central frequency (8.2 GHz) can be seen in Fig. 9. and the corresponding axial ratio in Fig. 10. The reflection coefficient remains below -14 dB in the whole working band.

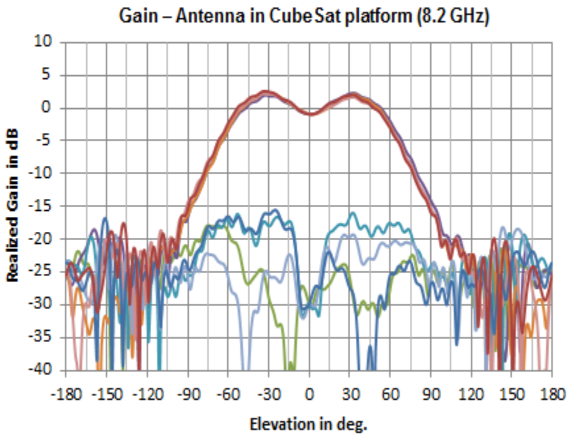

Fig. 9: Measured gain radiation pattern (8.2 GHz)

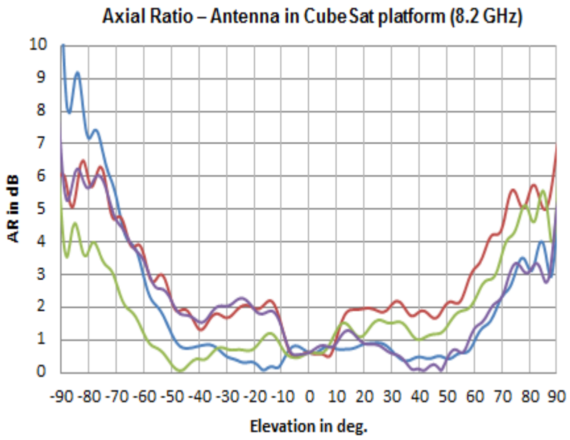

Fig. 10: Measured axial ratio (8.2 GHz)

VII. CONCLUSION

A compact X-band antenna concept capable to provide an isoflux radiation pattern with circular polarization has been presented. The antenna has been optimized for a nano-satellite platform of type CubeSat 3U that imposes an important volume constraint. The proposed antenna solution is based on a miniaturized helix topology connected to a printed feeding circuit and arranged over a corrugated ground plane. The simulation, manufacturing and measurement of the antenna have been described. Despite the no compliance of some specifications, the antenna concept seems to work satisfactorily and a further improvement of the mechanical assembly should approach the measurements to the theoretical performance.

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