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Compact Helical Ring Antenna for Iridium Communication on UAV

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Abstract:

The ENAC UAV team participates to a challenge named Fly2Corsica.

The aim of this project is to link the French Riviera to the Corsica Island with a small electric UAV.

To achieve a radio link between the French Riviera and Corsica (Fly2Corsica project), the ENAC UAV team plans to use the Iridium satellite service. To render this possible, a small antenna with good efficiency and pure circular polarization is required to optimize the link budget.

We present an antenna that fulfils this requirements.

Keywords: UAV antenna, small circular polarization antenna, Iridium antenna, helical ring antenna.

1. Introduction

The ENAC UAV team participates to a challenge named Fly2Corsica.
The aim of this project is to link the French Riviera to the Corsica Island with a small electric UAV. The distance between both points is about 185 km. The endurance of the UAV is limited to about 4 hours : a compromise has been found between the speed and the consumption to fly near the maximal range point.
A telemetry from the UAV is necessary all along the flight to get the flight information on the Ground Control Station. This is mandatory by the French Regulator to have the UAV position.
The radio range of a GSM base transceiver station is too limited to maintain a transmission with the UAV. A solution is to use a satellite communication service like Iridium. To render possible the transmission between the UAV and the satellite with an optimal link budget, we need a small and light antenna with a good efficiency and circular polarization. The well-known commercial Iridium antennas are based on helix technology (SARENTEL SL3101) or on patch design (PN# 500644).
In this article, we propose as an alternative solution an antenna that we have patented [1]. This antenna fulfils the requirements of the Iridium service. This antenna is constituted by a ring made of 8 metallic turns. With an appropriate feeding, the radiation can be oriented towards only the upper half-space with a pure circular polarization regardless of the nature of the support. Besides, its size can be reduced without using high dielectric materials which would increase the weight.
This article is organized as follows. Firstly, the history of the Fly2Corsica project is described. Secondly, we explain the antenna principle with his design and his feeding. Then we present simulation results from which we deduce the performances in terms of radiation pattern, bandwidth, efficiency and size.

2. Project description and history

2.1 History of the project

Fly2Corsica project has started as a collaborative student project between ISAE and ENAC in 2009. The objective is to fly from the French Riviera to Corsica with the smallest possible electrically-powered UAV. The chosen trajectory is to go from Menton to Calvi, which represent a distance of approximately 185km, at an altitude of 100m above the sea. A first attempt has been made in June 2010 without success. An other attempt is planned for June 2011, with noticeable improvements for the protection of the flight envelope of the aircraft. The latest version of the plane, called *Spirit Of Corsica*, is shown in Figure 1. It is a 1.5m wing span aircraft. The weight is around 2kg and more than half of it is coming from a 3-cells Lithium-Polymer battery of 210Wh.

Figure 1: Spirit Of Corsica

2.2 Aircraft design

The design of this aircraft has been done using a home-made tool [2,3] that sweep over a wide range of settings such as wing span and wing area. One of the main constrain for the final wing span is the size of the battery pack. With tree cells of 275x55mm each, the only suitable location is inside the wing. This configuration almost forbids to have some dihedral on the wing, that would increase the natural stability of the plane. The directional and longitudinal stability is provided by a pretty large tail with a long arm from the centre of gravity, which makes it difficult to balance.

2.3 Autopilot system

The autonomous navigation and stabilisation system used for this mission is the Paparazzi System [4,5] developed at ENAC (Fig. 2). An autopilot board Tiny2.1 provides the attitude stabilisation, the navigation by means of a small GPS receiver, and a bidirectional link with the ground station. The ground station itself is a regular laptop that runs a set of programs including a graphical interface that allows to monitor and control the flight plan of the UAV. The modem we use for normal data link is a Xbee Pro 2.4GHz. Due to the French regulation, the emitting power is limited and for the first flight to Corsica, this link was lost after 3.6km despite of the use of a directional antenna on the ground.

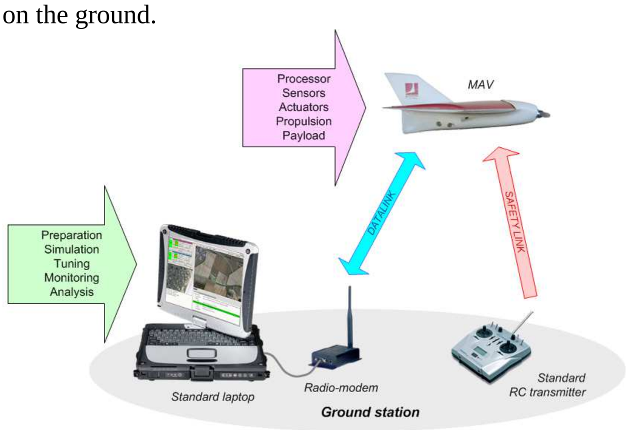

Figure 2: Paparazzi System overview

2.4 GSM communications

For the first attempt, a GSM module was planned to be used as a secondary telemetry link to keep track of the plane after loosing the radio-modem connection. The choice of the GSM module (TELIT 864 GSM/GPRS) was made because of its small size and affordable cost. An other reason was that the planned track for the crossing is close to the commercial ferry line between Nice and Calvi, and that high gain GSM antennas are supposed to be oriented on this axis. This let us hope for a better range with the GSM module than the radio-modem. Two main drawbacks arise from this solution. First the GSM network is not covering the whole trajectory. It means that we would have lost the communication during the first attempt even without the other technical issues that led to the lost of the plane. The second issue is the size and weight of the commercial antenna we have used. It is a flap antenna of 110x20mm for 8 grams that needs to be hold vertically. Thus, the only possible location is inside the tail of the aircraft in order to avoid an increases of the drag. Despite of its small weight, the long arm between the tail and the centre of gravity increase the aft centring of the plane. The new design of the tail for the second attempt, with a bigger surface and a further position, without modifying the main body, makes it almost impossible to use such antenna.

For this reasons, the opportunity to use a Iridium modem has been studied. This solution would allow to maintain the communication during all the flight. An other reason to consider this option is that Iridium modules are getting smaller every year and they are now fitting inside the main fuselage of the plane. The remaining issue is the antenna that still need to be as small as possible, with a good efficiency and the possibility to place them close to the centre of gravity. The design of this antenna has been done by the LETA team from ENAC.

3. Antenna Principle

3.1 Half-directivity

To obtain directivity we combine two radiating modes, both with a torus radiation pattern and a circular polarization. We assume that the first torus is oriented along the *x*-axis, whereas the second is oriented along the *y*-axis. If there is a phase shift of ±90 degrees between them, one can prove that the total radiation will be null, (resp. maximal) in the +*z*-direction, and maximal (resp. null) in the -*z*-direction (Fig.3).

The direction of the null and maxima depends on the sign of the phase shift while the direction of the circular polarisation depends on the direction of the winding turns.

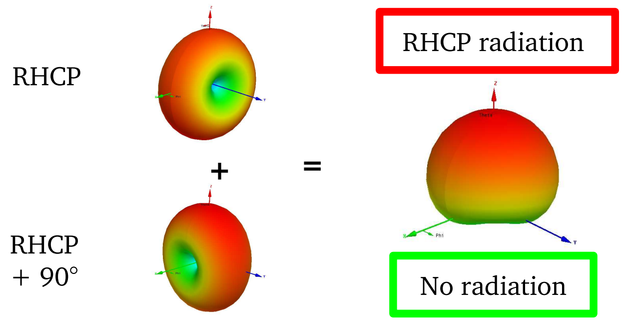

Figure 3: Half-directional radiation pattern

To obtain the first torus radiation pattern (along the *x*-axis) with a circular polarization, , a solution consists in a magnetic dipole and an electric dipole, both collocated and aligned with the *x*-axis [6, 7] (Fig. 4).

Both dipoles present a natural phase quadrature and their magnitude can be equalized by tuning the length *S* of the electric element and the diameter *D* of the loop. For an axial ratio equal to unity, this yields the simple relation

$$\pi D=\sqrt{2S\lambda} \quad [1]$$

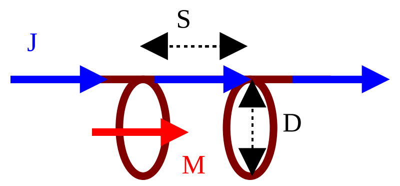

Figure 4: Co-located magnetic (M) and electric (J) dipoles

The second torus radiation pattern (along the *y*-axis) with a circular polarization can be obtained in the same way.

Thus, the two radiating modes can be obtained via two helical antennas oriented along the *x* and *y* axis.

We can collocate the two helical antennas by using a helical antenna, which shape is either a ring, a square, or a cross.

In order to prevent unwanted mode coupling, we choose to employ the ring shape. When the number of turns is a multiple of four, we have an invariance of the structure under rotation of 90°.

In Fig. 5 an example of an 8-turns design is given.

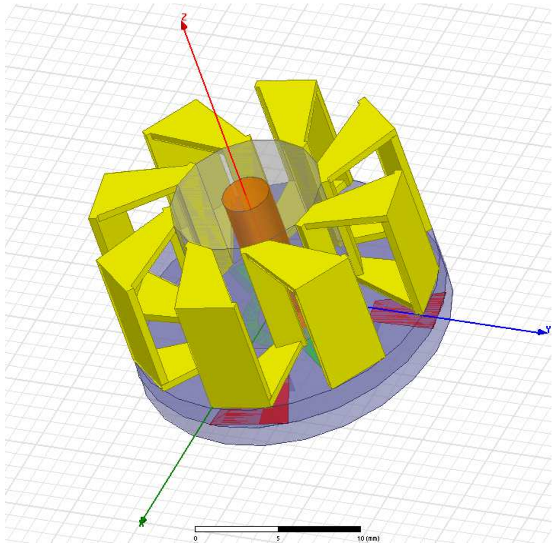

Figure 5: Antenna structure

3.2 Antenna feeding

For the antenna feeding, a solution is to use two feed probes placed on the *x*- and *y*-axis to excite the two orthogonal modes [8]. The phase shift between both probes allows to control the direction of the radiation. This can be realized by means of an 3dB hybrid splitter. The sense of the circular polarization corresponds to the left-hand or right-hand orientation of the helix.

Alternatively, only one feed probe can be used by adding an internal metal piece to realize a controlled mode coupling. This coupling element is inserted so as to obtain the quadrature excitation. To do so, the element is placed at ±45° from the position of the feed probe, with a ± sign chosen to orient the radiation towards the direction ±*z*.

In this article, we use only one feed probe that is electrically coupled to the antenna by means of a metallic disk placed below the ring. A magnetic coupling would also be possible using classical loops. Electric coupling with one probe is chosen here because it yields a simpler design without extra components.

3.3 Antenna design.

For a fixed number of turns, the frequency is matched by adjusting the diameter of the ring, the height of the turns and the distance between the ring and the metallic disc.

The circular polarization is matched by adjusting the height of the turns to the diameter of the ring, and from the coupling piece between both modes.

Note that the antenna efficiency depends on its final size: the smaller the size is, the smaller the bandwidth and efficiency are. Nevertheless, As explained in [9], this size can be strongly reduced compared to a half-wavelength antenna without high dielectric materials inclusion.

In [9], we have also shown that, in such structures, the field remains mainly confined inside the helical part. Hence the sensitivity of this antenna to its surrounding is low.

Finally, the proposed antenna is of height 11.5mm and diameter 20mm.

4. Simulation results

The simulations are performed with Ansoft HFSS.

We display in Fig. 6 the 3D radiation pattern. As expected, the antenna is half-directional, i.e. it only radiates towards the half space $z > 0$.

The maximal right-hand circular polarized (RHCP) gain is of 3.5dBi. The antenna is designed to have a beamwidth wide enough so as to maintain good performances of the antenna even at low elevation angles. This is due to the configuration of the Iridium constellation.

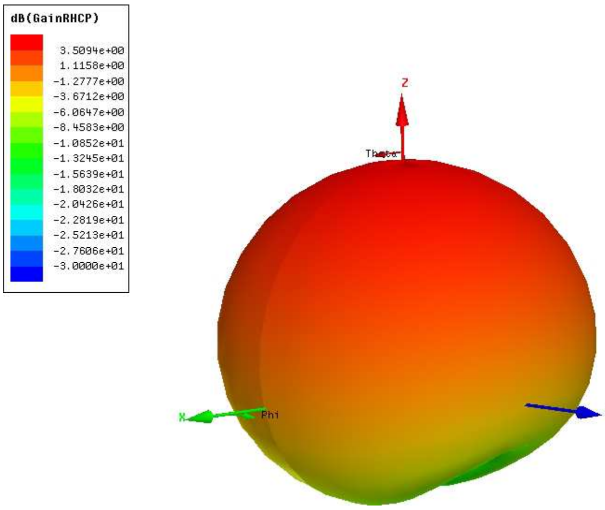

Figure 6: Antenna RHCP gain pattern (dBi)

In Fig. 7, the radiation pattern in the *x0z* plane is represented for both RHCP and the LHCP gain.

In the 0*z* direction, the front-to-back ratio is 9.4dB and can be improved by optimizing the design of the antenna.

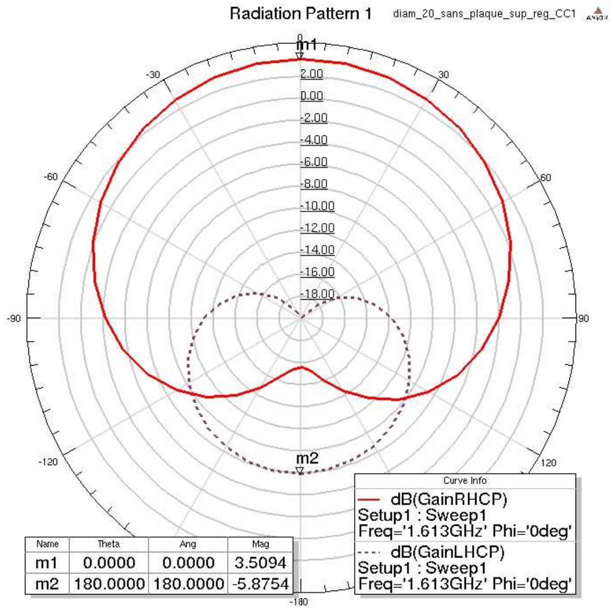

Figure 7: Antenna RHCP and LHCP gain pattern (dBi)

In Fig. 8, the reflection coefficient (S11) of the antenna probe is plotted. We obtain a bandwidth (VSWR =2) of 22Mhz for an input impedance of 50 Ohms.

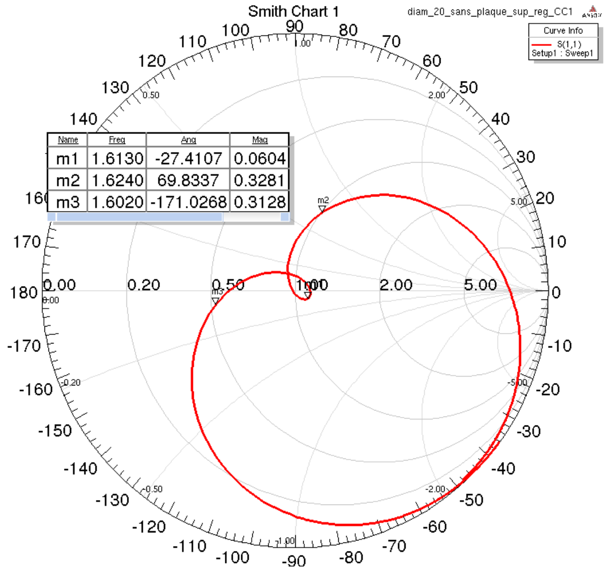

Figure 8: Smith chart of the antenna reflection coefficient (S11)

In Fig. 9, the axial ratio is plotted in the *x0y* plane at the minimal, central and maximal values of the frequency band, i.e. at 1.6, 1.613, and 1.626Ghz, respectively. We observe that the radiation is almost purely RHCP regardless of the direction of observation. At zenith (+*z*), the axial ratio remains smaller than 1.5 in all the bandwidth. For low elevation angles, where some Iridium satellites may be located, the performances in terms of circular polarization remains very good.

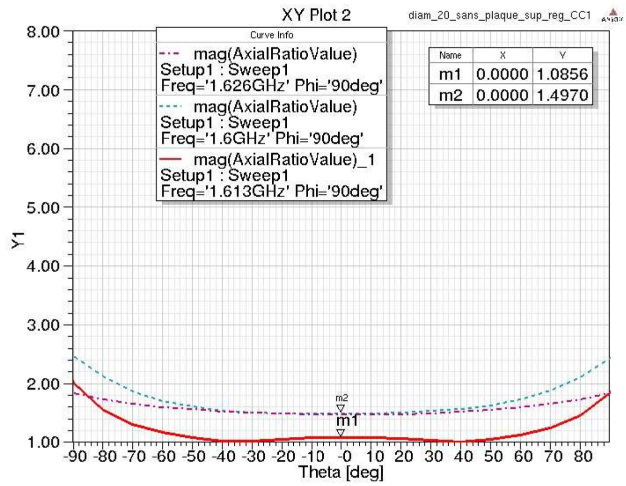

Figure 9: Antenna axial ratio at the minimal (blue dashed curve), central (continue red curve), and maximal (magenta dashed curve) frequencies of the bandwidth

5. Performances

To summarise, the performances of the helical ring antenna we propose can be listed as follows:

- Minnimal, central, and maximal frequencies: 1600, 1613, 1624 MHz (easily tunable).
- Polarization: Right-hand circular polarized (RHCP)
- Axial Ratio : <1.5 atzenith
- Gain: +3.50 dBi at zenith
- Efficiency: 80%
- Beamwidth: Half space
- Bandwidth (VSWR=2): 22 MHz
- Impedance: 50 Ohms
- Dimensions (diameter x height): 20 x 11.5mm without connectors.
- Weight: to be estimated according to the technology used

This antenna has not been realized yet. Nevertheless, a four turn prototype has already been constructed to confirm the presented properties, ie, the self-directivity in an half space with good circular polarization radiation.

The great interest of this compact helical ring antenna technology is its immunity to de-tuning in the presence of surrounding materials, like metallic or dielectric support when it will be mounted on the UAV.

The performances in terms of efficiency and polarization will remain satisfying regardless of the constellation configuration, allowing the antenna to maintain a connection during all the flight.

6. Conclusion

A new structure of antenna has been proposed to achieve a half-directional pattern without any reflector and with a very good right-hand circular polarization. Besides, since the electromagnetic fields are highly confined inside the helical part without extra materials like ceramic dielectric, this antenna presents a low sensitivity to its environment for a light weight. These properties render this antenna highly adapted to be integrated on an UAV to perform a long range connection using the Iridium satellite services.

7. References

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