DESIGN AND CHARACTERIZATION OF A TELEMETRY SYSTEM FOR FLIGHT TESTS IN LIGHT AIRCRAFTS

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Keywords: *Telemetry, antennas, aircraft, transceiver, pointer*

Abbreviations

A/D	"Analog-to-Digital"
CEA	Center for Aeronautical Studies
CEA-FDAS	Center for Aeronautical Studies - "Flight Data Acquisition System"
CEA-UFMG	Center for Aeronautical Studies – Federal University of Minas Gerais
FHSS	"Frequency-Hopping Spread Spectrum"
GPS	"Global Positioning System"
ISM	"Industrial, Scientific and Medical"
MAP	"Manifold Absolute Pressure"
PDA	"Personal Digital Assistant"
RSSI	"Received Signal Strength Indication"
RS	"Recommended Standard"
TIA-EIA	"Telecommunications Industry Association-Electronic Industries Alliance"
USB	"Universal Serial Bus"

Abstract

This work presents the development and test results of a telemetry system for use in either manned or unmanned aircraft. Such system demanded the design of many sub systems to transmit the telemetry signal over wire and wireless links, thus reducing or attenuating interference. The results presented were obtained from the data received using different configurations and types of antennas, including a servo-controlled pointing device at ground side, while at the aircraft an Omni directional antenna was used.

1 Introduction

The Center for Aeronautical Studies of the Federal University of Minas Gerais (CEA-UFMG) was founded in the 1960s and have been acting as a solid development center for the aeronautical industry.

Since its creation, many aircraft and related products and services were designed and built. Among their aircraft the CB-9 "Curumim" is a high performance ultra light bi place that has shown as an excellent platform for flight testing, so in the past years it has received all the necessary instrumentation for such activity.

In 2008 was the opening of CEA's Hangar at Conselheiro Lafaiete airport, located about 96 kilometers apart from Belo Horizonte, capital of Minas Gerais state. This new facility allowed the increase of research and development activities in applied aeronautics. CEA is now, one of the few research centers worldwide that offers his students the opportunity to ally theory and practice, resulting in a final product totally operational, the aircraft.

After the inauguration of CEA's hangar and the good results with CB-9 flight test activities, one idea came to mind, a telemetry system that could allow the real time analysis of many aircraft flight data. This system could also be used in other aircraft developed by CEA-

UFMG. Moreover, it could provide the students of Flight Test class an opportunity to practice the theory learnt in the classroom.

Telemetry systems bring many advantages to aircraft flight tests. Unlike traditional data recording systems, where the data is available after the aircraft has returned, a telemetry system allows analysis of real time aircraft (and pilots) data, thus allowing the ground crew to validate a procedure/flight test according to the regulation, and suggest changes, as necessary, reducing the total procedure time, number of takeoffs and landings. Consequently, this raises the crew safety [1] and reduces the total cost of the flight tests.

2 The System

The presented telemetry system is used in conjunction with the data acquisition system CEA-FDAS [2], allowing several flight parameters to be acquired. A block diagram of the whole system is presented in Fig. 1. The upper side of the diagram presents the Transducer/GPS block, responsible for converting attitude, position, air data, engine and other parameters into electrical signals, which are recorded in solid state media by the CEA-FDAS block. The signals are then routed to the transceiver block which comprises a radio transceiver and an Omni directional antenna. At the bottom of the diagram there is the receiver antenna. In fact a sort of antenna types including a directional antenna attached to a servo-controlled pointing device was used. The next block is the radio transceiver that also contains the RSSI sampling and signal conditioning circuits for cable transmission of information to the next block, the PC used for processing analysis and presentation of aircraft data.

3 The Aircraft

To accomplish the flight tests, the CB-9 "Curumim" was used. This aircraft, seen in Fig. 2, is an ultra light weight bi place. It is built in wood and uses Limbach L2000 EB1 engine. Fig. 3 presents the three views of the aircraft.

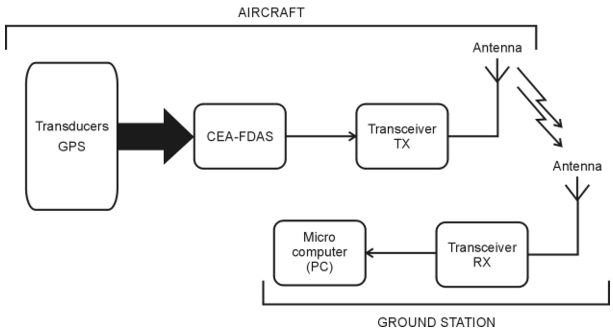

Fig. 1. System general view

Fig. 2. CB-9 "Curumim" aircraft

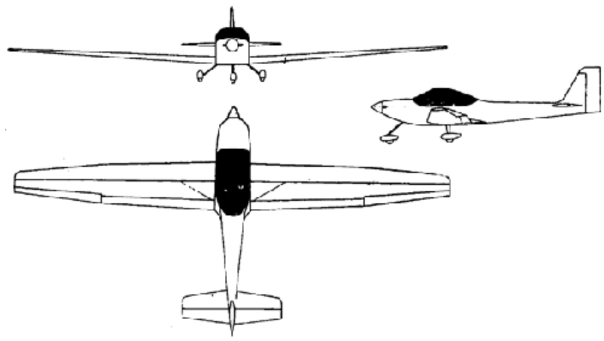

Fig. 3. CB-9 "Curumim" three views

3.1 The aircraft equipments

Fig. 4 presents the block diagram of the installed aircraft equipments.

As transducers, the following equipments were installed in the aircraft:

- Linear potentiometers, to obtain information about the control surfaces and the throttle positions;
- Optical tachometer, to measure the propeller RPM;
- Pressure sensor, to measure the Manifold Absolute Pressure, MAP;
- Load cell, to measure stick force;

- Pitot tube with two “flags”, to measure the airspeed and angle of attack (α) and sideslip (β);
- Inertial platform, to measure the three-axis angular and linear accelerations and, hence, the aircraft attitude.
- A Garmin GPS III sending aircraft position, heading and ground speed through its serial port at a rate of 0.5Hz.

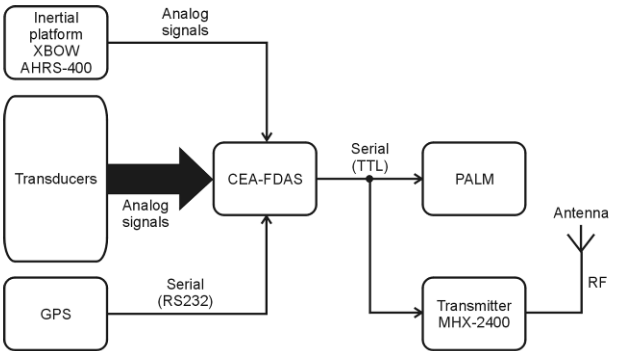

Fig. 4. Block diagram of the aircraft systems

The main element of the embedded components is the flight data acquisition system, CEA-FDAS, which acquires all transducer and inertial platform analog signals as well as receive the serial GPS data. Then the CEA-FDAS organizes all that information and send them as data packets in its output serial port.

A PDA model Palm TX, produced by PalmOne, is used as an interface for data presentation and also store this data in a solid state memory.

A transceiver model MHX-2400 from “Microhard Systems” for transmitting the data. The main features of this transceiver are, according to its operational manual [3]:

- Operational frequency on the free band ranging from 2.4 to 2.4835 GHz;
- FHSS Modulation technique;
- Standard TIA-EIA-232 serial port, with transmission rate adjustable from 2400 to 115200 bps;
- RSSI output, that allow an evaluation of the intensity of the signal received;
- Reduced weight and dimensions;
- Omnidirectional antenna with 2.2 dBi gain.

Fig. 5 presents the equipments installed in the aircraft.

Fig. 5. Flight test equipments

4 Ground Station Equipments

Fig. 6 present the block diagram of the equipments used in the ground station.

Three antenna types were used for estimating the coverage of the radio link:

- Omni directional antenna [4];
- Sector panel [5];
- Directional antenna [6];

All the antennas were manufactured by “HyperLink Technologies” and work at the ISM 2.4GHz band, the same as the transceiver. The polarization is vertical and the characteristic impedance is $50\,\Omega$. The matching of such parameters between the antenna and the radio transceiver reduces the losses by reflection to a negligible level [7].

The ground station uses the same transceiver as the aircraft; model MHX-2400 from “Microhard Systems”. Given the physical separation between the place where the antenna system should be placed and the telemetry room (Fig. 7) it was decided to keep the transceiver close to the antenna and extend a wire transmission line from the radio to the telemetry room. Due to the long length of cable needed to link these two places, as well as the proximity with the hangar energy cables, using the same baskets and conduits, the RS-232 (TIA-EIA-232) interface present in radio transceiver and at in the PC might suffer from severe attenuation or interference, so a level translator was used to convert from RS-232 to RS-485 (TIA-EIA-485) which is more adequate to this kind of application.

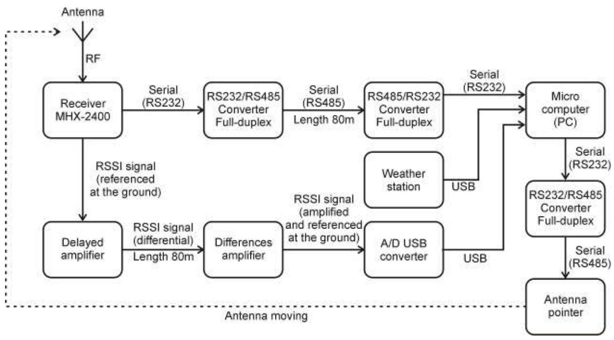

Fig. 6. Ground station block diagram

In order to estimate the quality of communication between the aircraft and the ground station it was used the RSSI signal available at the transceiver. Such signal consists of fixed width pulses of approximately 3ms spaced by 27ms (30ms total period). The amplitude of these short pulses is proportional to the intensity of the received signals. The maximum amplitude of the RSSI signal is 1.4Volts, referenced to ground level. Fig. 8 presents the waveform the RSSI signal, captured obtained from the transceiver.

Fig. 7. Aerial photo of CEA's hangar

The RSSI signal should also be transmitted from the antenna tower to the telemetry room, but since it's a low amplitude ground referenced signal it would also suffer from common mode noise (besides the attenuation and interference).

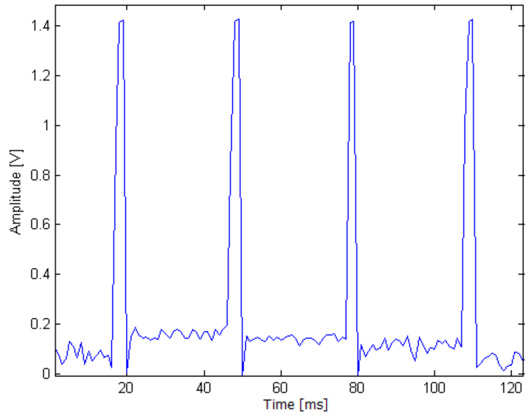

Fig. 8. Original RSSI signal

To cancel the common mode noise, it was used the differential transmission of the signal RSSI. It consists in translating the voltage signal from one line referenced to ground to a pair of lines in which the voltage difference between them represents the amplitude of the original signal. At the other side of the line the noise added to both lines is equal and the voltage difference between the lines still to represent the original signal.

At the other side of the line (i,e. at the telemetry room) it was also necessary to amplify the recovered RSSI signal to match the maximum amplitude with the input of an A/D converter model "Ni USB6009" manufactured by "National Instruments". Such converter is connected to PC by an USB connection. See Fig. 9.

Fig. 9. A/D converter used to sample the recovered RSSI signal

Fig. 10 presents the signal RSSI path to the telemetry room PC. The nature of signal interconnection, either differential or ground referenced can be noticed.

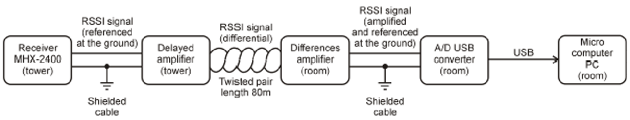

Fig. 10. RSSI signal path

The weather data (pressure, humidity and temperature) in the ground station were obtained by a weather station model USB "Weather Board" SEN-08311 manufactured by "Sparkfun Electronics", see Fig. 11.

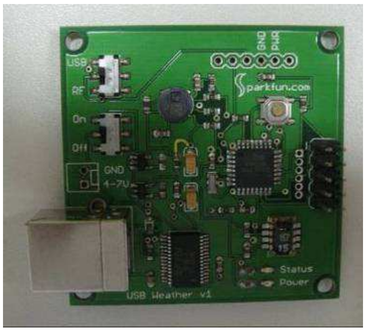

Fig. 11. Weather station

Fig. 12, Fig. 13 and Fig. 14 present the installed antennas in the telemetry tower.

- Omni directional antenna [4];

Fig. 12. Omni directional antenna

Operating Frequency: 2,4 to 2,5 GHz
Gain: 8 dBi
Impedance: 50 Ohm
Horizontal beam width: 360°
Vertical beam width: 18°
Polarization: Vertical

- Sector panel antenna [5];

Fig. 13. Sector panel antenna

Operating Frequency: 2,4 a 2,5 GHz
Gain: 14 dBi
Impedance: 50 Ohm
Horizontal beam width: 90°
Vertical beam width: 15°
Polarization: Vertical

- Directional antenna [6];

Fig. 14. Directional antenna

Operating Frequency: 2,4 a 2,5 GHz
Gain: 24 dBi
Impedance: 50 Ohm
Horizontal beam width: 8°
Vertical beam width: 8°
Polarization: Linear

Fig. 15 and Fig. 16 present the installed equipments in the tower and in the telemetry room.

4.1 Antenna Pointer

It was developed an automatic antenna pointing system that moves the ground station antenna, pointing to the aircraft during its flight. The development of such system is justified by the possibility to provide a greater and better quality signal thus enhancing the coverage area of the telemetry system.

The pointing system uses GPS data to calculate the position of the aircraft then uses this information to change the azimuth and elevation of the ground station antenna in such a way that the main lobe of the antenna points to the aircraft.

Fig. 15. Equipments on the tower

The change in azimuth and elevation is performed by a couple of DC motors adapted to work as servo-motors. Due to the great torque, low cost and availability, a couple of automotive wind-shield DC motors with reduction gears were used.

Fig. 16. Telemetry box

Fig. 17 shows the pointer during a CB-9 “Curumim” Flight test.

Fig. 17. Antenna pointer during the flight test

4.2 The Ground Station Software

For presenting the telemetry data acquired from the aircraft, it was developed a Matlab®/Simulink® interface together with the AeroSim blockset. The latter is a toolbox for aeronautical simulation. This toolbox supplies, for example, the virtual aircraft instrument models.

Fig. 18 presents the block diagram of the ground station software. It can be seen that the “ground station” has the telemetry, RSSI and weather station data as inputs. It processes this information and provides the pointing position and the data to the virtual instruments model as output. During its operation this system does not require user intervention.

The data presentation interface, Fig. 19, delivers information about some aircraft parameters in the form of common aviation instruments, see Table 1.

5 Characterization of the Proposed System

To characterize the proposed system a flight test campaign was prepared and performed aiming to: i) evaluate the signal quality taking into account that the aircraft body interferes an modifies the radiation pattern of the transmitting antenna; ii) evaluate the ground station antenna radiation characteristics; iii) evaluate the system coverage area; iv) evaluate the performance of the antenna pointer.

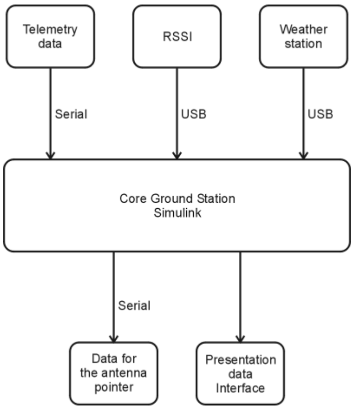

Fig. 18. Block diagram of the "Ground Station"

Fig. 19. Data presentation interface

5.1 Signal Quality Test of the Aircraft Installed Antenna (Butterfly Test)

The purpose of this test is to evaluate the aircraft isotropy, i.e., evaluate if the signal transmission occurs equally in all directions.

Although the installed antenna is omnidirectional, the presence of the aircraft structure and other components creates an electromagnetic wave coupling with them, thus deforming the original antenna radiation pattern.

As seen in Fig. 20, this procedure consists in flying four times over a waypoint keeping the aircraft in a height and attitude that allows its antenna to be in the main lobe of the receiving antenna. The four passes correspond to two perpendicular directions in both ways for each direction. The distance D, in Fig. 20, is defined regarding some flight safety criteria in order to allow that the aircraft to be maintained in a minimum height but still in the main lobe of the receiving antenna.

Table 1. Ground station indication

Indication	Unit
Airspeed indicator	Mph
Artificial horizon	
Altimeter	Ft
Climb indicator	ft/min
X axis acceleration	G
Y axis acceleration	G
Z axis acceleration	G
X axis angle	Degrees
Y axis angle	Degrees
Z axis angle	Degrees
Ground station atmospheric pressure	Pa
Ground station temperature	℃
Ground station relative humidity	%
Aircraft distance to the ground station	Km
RSSI signal	V
Angle of attack	Degrees
Sideslip angle	Degrees
Throttle position	%
Tachometer	RPM
Air manifold pressure	kPa
Aileron position	Degrees
Elevator position	Degrees
Rudder position	Degrees
Stick force	Kgf

During the flight, the geographical position (latitude and longitude) and the RSSI signal level are stored, and then analyzed to obtain the radiation figures in four directions: nose, tail, left and right.

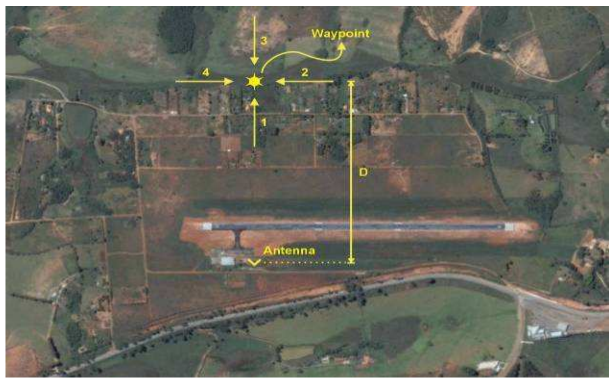

Fig. 20. Procedure for aircraft isotropy test

5.2 Ground Station Antenna Performance Test (Circle Type Test)

The purpose of this test is to obtain the radiation pattern of the receiving antenna.

The test procedure consists in flying over a circular trajectory at a constant radius around the receiving antenna, located at the center of the circle, see Fig. 21. The height needed to perform this test shall allows the aircraft antenna to be in the main lobe of the receiving antenna (similar to the previous test, just considering that the distance D, in this case, is the circle radius).

During the flight the geographical position information, signal strength level and base distance shall be stored in the same way as the previous test.

This test provides important information about the antenna radiation diagram considering the influence of the environment around it. The resultant pattern can be compared with the antenna diagram supplied by the manufacturer.

5.3 Signal Attenuation Test for the Distance Variation (Distance Type Test)

This test allows estimating the telemetry system coverage by measuring the strength of the signal while the aircraft approaches or moves away from the antenna.

The test procedure consists in maintain a straight flight trajectory aligned with the main radiation lobe of the receiving antenna installed on the telemetry tower.

The trajectory shall be done in both directions, see Fig. 22. The maximum coverage is defined by the distance where the loss of communication occurs (or as in the previous tests, by safety reasons).

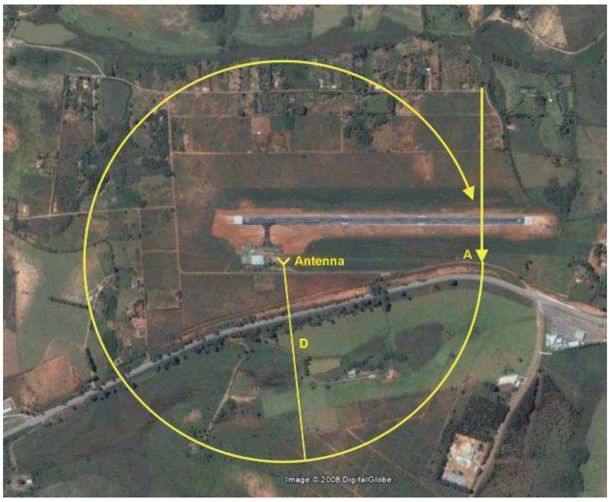

Fig. 21. Procedure for obtaining the radiation pattern of the antenna on the ground station

During the flight, geographical position and RSSI signal level data shall be recorded, allowing the plotting of RSSI signal level versus the distance.

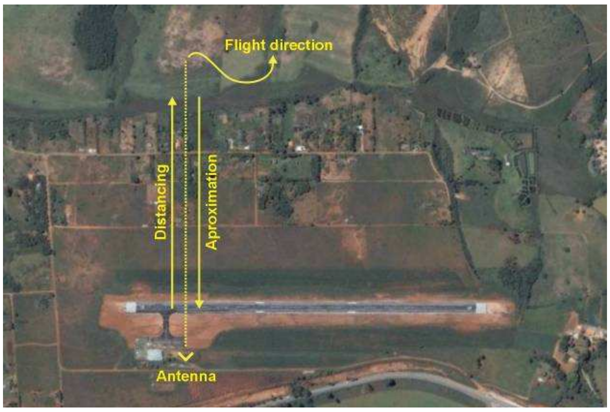

Fig. 22. Procedure for the signal strength measurement versus the distance

5.4 Directional Antenna Pointer Test

This test procedure aims the evaluating of the antenna pointer efficiency. To perform such evaluation is necessary to flight over a path that allows the movement in both the azimuth and elevation axes, which implies that both aircraft geographical position and altitude have to change.

As presented in Fig. 23, for this test, semicircular fight paths were performed: semicircles A, B, C and D. The path of each radius is Ra, Rb, Rc and Rd, respectively. Each path has different height, in order to allow the pointing device to move the antenna in both axes.

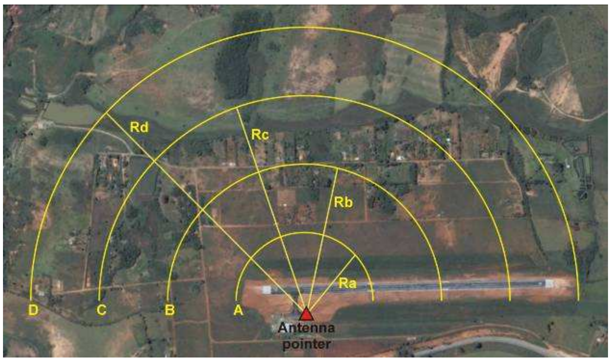

Fig. 23. Proceeding for the pointer test

As in previous tests, during the flight the geographical position and RSSI signal level data were recorded, allowing the evaluation of signal intensity according the aircraft position.

6 Results Presentation

The five test campaigns demanded eleven flight hours. Here follows some results obtained with these tests:

6.1 Butterfly Type Test

The result is shown in Fig. 24. The radiation diagram obtained for the aircraft is presented in Fig. 25. It is possible to notice that the tail direction has a higher radiation level than the nose. The same for the left side comparing with the right side.

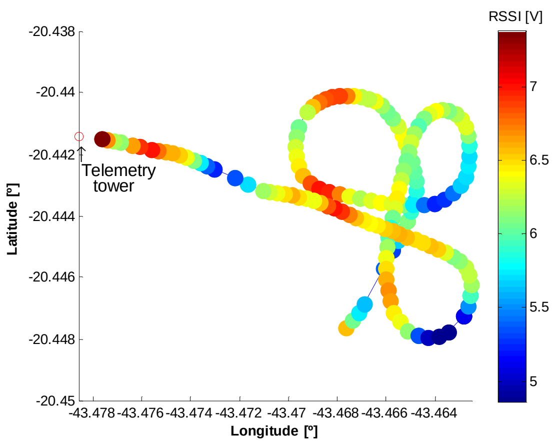

Fig. 24. Trajectory made and RSSI signal variation

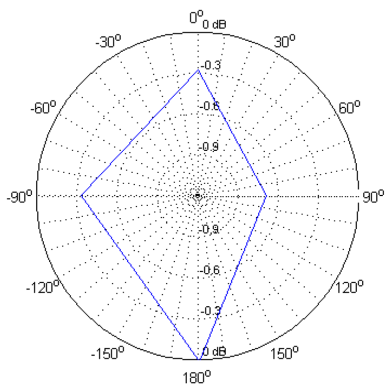

Fig. 25. Aircraft radiation diagram

6.2 Circle Type Test

Fig. 26 shows the plot of trajectory versus RSSI signal variation.

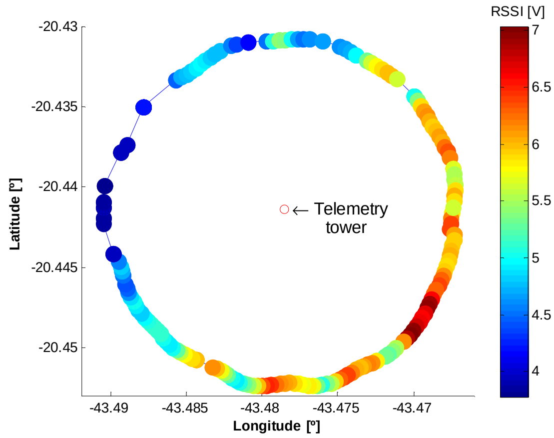

Fig. 26. Trajectory and variation of the RSSI

The telemetry tower antenna radiation diagram, for a sector panel antenna, is presented in Fig. 27.

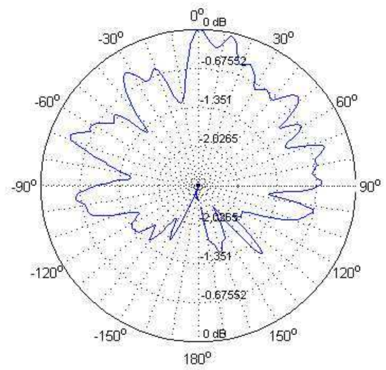

Fig. 27. Actual radiation diagram

Fig. 28 presents the radiation diagram provided by the sector panel antenna manufacturer. The comparison between Fig. 27 and Fig. 28 shows the similarity between the measured and the theoretical pattern.

Fig. 29 and Fig. 30 present the radiation diagrams for the omnidirectional and directional antennas at the left, along with the theoretical diagram for both at the right.

The similarity can be clearly noticed. The differences arise due to the presence of the environment around the antennas and by other sources of signals at the same frequency band (ISM).

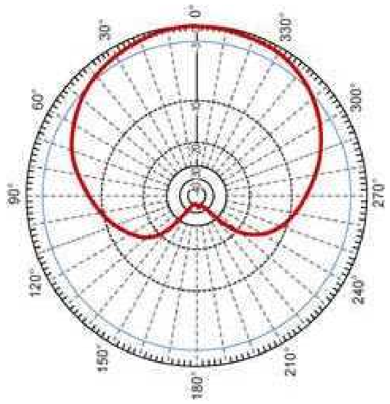

Fig. 28. Supplied radiation diagram

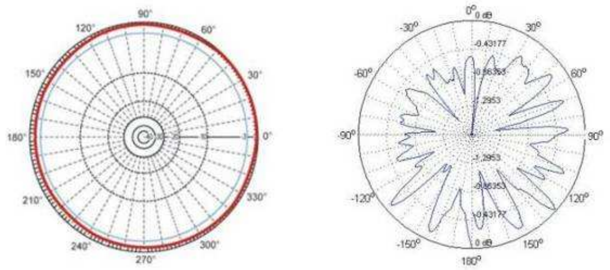

Fig. 29. Omnidirectional antenna radiation diagram

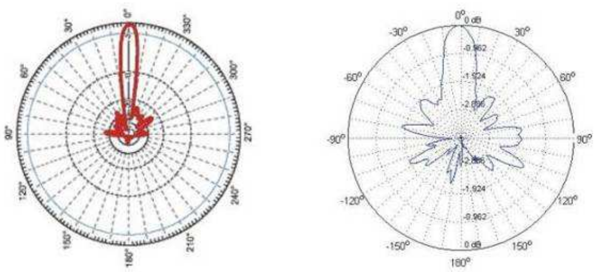

Fig. 30. Directional antenna radiation diagram

6.3 Distance Type Test

Fig. 31 presents the performed trajectory and Fig. 32 presents the RSSI signal variation versus the distance from the directional antenna.

In Fig. 32 it is possible to notice that the maximum distance obtained was 32 km. For the other distance tests, the maximum range was 30 km, for the sector panel, and 26 km, for the omnidirectional antenna.

6.4 Antenna Pointer Test

For the antenna pointer, Fig. 33, presents the performed trajectory using different colors. In red is the path in ground beginning of the runway, while the green, yellow, pink, blue and black lines are the semicircular trajectories suggested in Fig. 23.

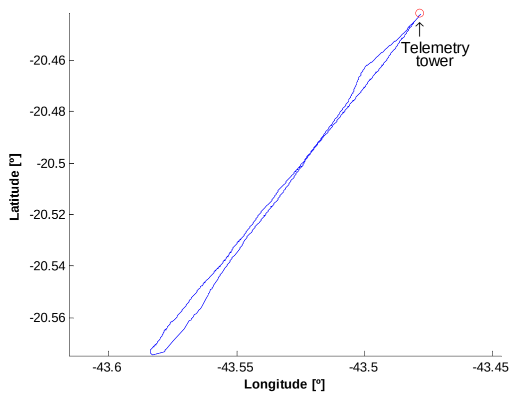

Fig. 31. Performed trajectory

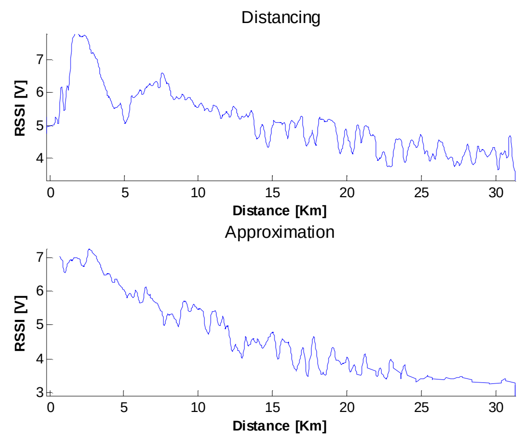

Fig. 32. RSSI signal variation

To evaluate the performance of the pointing device, the RSSI signal variation versus distance was plotted for each semicircular path (Fig. 34). The horizontal reference line at each graphic represents the RSSI signal obtained for the same distance on the distance tests for the static directional antenna (see Fig. 22). Using this reference, it is possible to compare the signal level obtained with the pointer to the level obtained with a static antenna for the same distance from the aircraft to the receiving antenna.

From Fig. 34, it is possible to notice that for up to a distance of 0.8 km, the signal received using the pointer remained higher than the obtained with the static antenna, but from a distance beyond 1.14 km, the signal obtained using the pointer was lower than the obtained with the static antenna.

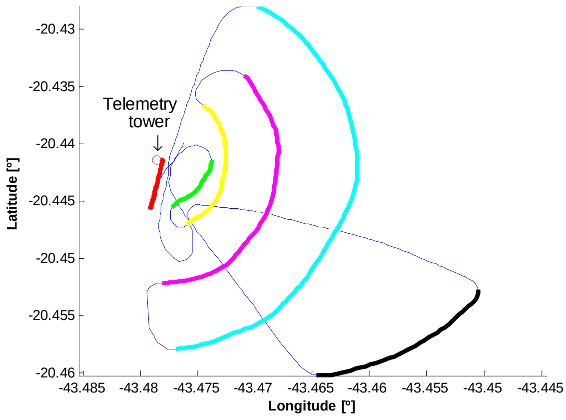

Fig. 33. Performed trajectory

To analyze this behavior, it is necessary to understand that that the pointer error is inversely proportional to the aircraft distance. This effect was noticed during the tests and can be justified by the relatively low refresh rate of position information from GPS to the pointer (0.5Hz). That explains the results obtained on the distances: 1.14 km, 1.97 km, 3.11 km and 5.08 km.

The apparently contradictory signal measurements at a distance of 0.8 km can be explained by the fact that the aircraft proximity is such that it ends up surpassing the pointing error, in other words, due to the low distance and the relatively high transmission power, 1 W, the signal level reaches higher values than the reference line.

Fig. 35 presents the trajectory versus RSSI signal variation for the pointer test. Finally, it is possible to conclude that the pointer presented a satisfactory performance, and it was not verified, in any moment, the loss of communication.

7 Conclusions

This work presented the design, proceedings and tests for the characterization of a telemetry system for light aircraft flight tests. According to the results, it is possible to conclude that the proposed system presents adequate performance to the proposed objectives.

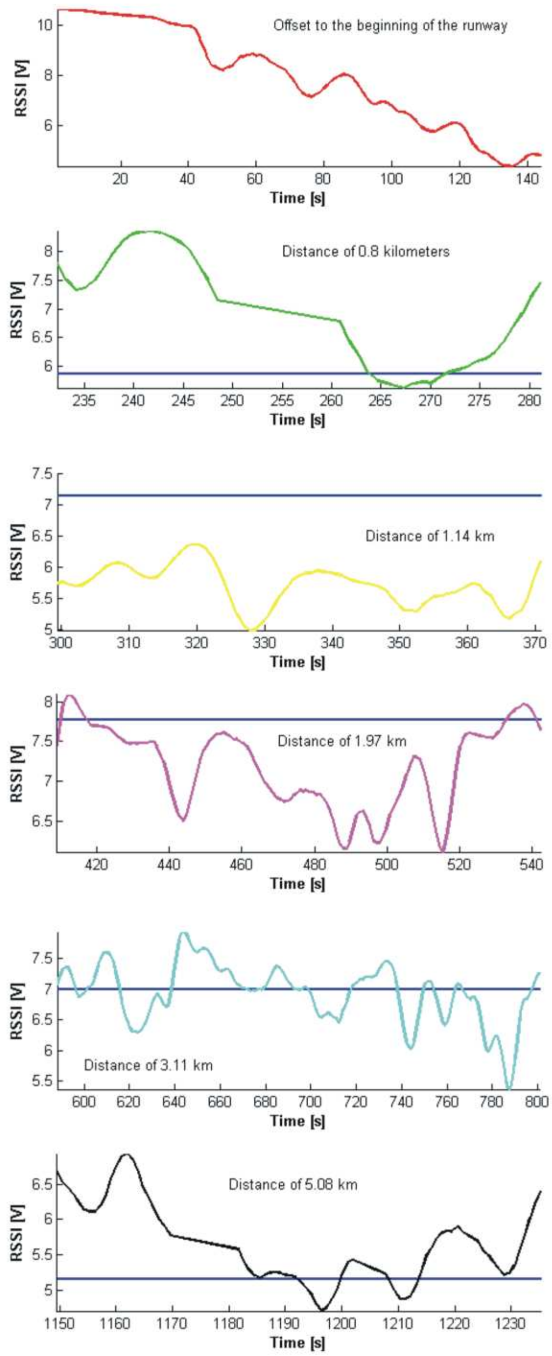

Fig. 34. RSSI signal variation by sector

The data displayed in the ground station, through virtual instruments, shows itself as a prudent choice for the educational goals that might arise for this system.

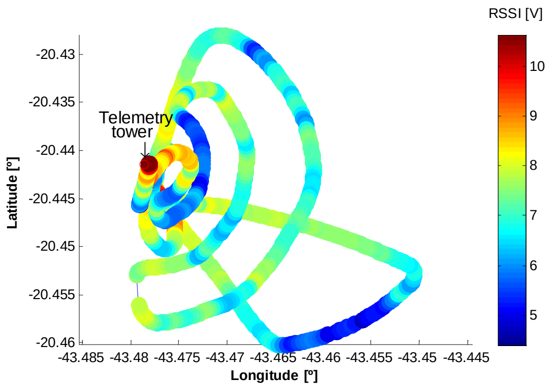

Fig. 35. RSSI variation over the performed trajectory

Besides, it was suggested that the maximum system distance when it is considered the sector panel and directional antennas, including the pointer, is above the obtained limits, once this distance was established by the occurrence of the defined maximum and not by the loss of communication, as occurred for the omnidirectional antenna. Even for the last antenna, the maximum distance obtained, 26 km, is enough to perform several kinds of flight tests.

Regarding the pointing device, it was possible to notice that its application is more indicated when it is necessary to maintain the aircraft at greater distances, above 15 km, from the ground station.

For closer distance flight tests, up to 15 km, where the limitation of test region in ninety degrees in the horizontal plane in front of the antenna is not critical, the use of the sector panel antenna shows itself as an adequate alternative.

In situations where the region limitations, provided by the sector panel, are limitation factors, the use of the omnidirectional antenna is adequate for distances below 10 km.

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