A Compact ADS-B Receiver for a 1U CubeSat

João Pinto[3], Tomás Almeida[3], Luís Pereira[3], Gonçalo Tavares[2,3], Carlos Fernandes[1,3], Alberto Cunha[3], Rui Rocha[1,3]
[1] Instituto de Telecomunicações, [2] INESC-ID, [3] Instituto Superior Técnico

Introduction

ISTsat-1 is a 1U CubeSat being developed at Instituto Superior Técnico / University of Lisbon in Portugal. Its payload is a compact Automatic Dependent Surveillance – Broadcast (ADS–B) system used to track aircraft positions.

Interest on space-based ADS-B has grown due to recent aircraft accidents that disappeared in remote areas away from ground tracking. Demonstration missions based on small satellites contribute to assess the viability of future space-based ADS-B services.

Our ADS-B system comprises a small form factor antenna and receiver fitting into the reduced space available aboard a 1U CubeSat. The antenna needs no deployment and the receiver design ensures high sensitivity for operation in LEO satellites. The mission consists in characterizing in-orbit the performance parameters of such receiver chain by correlating the collected ADS-B aircraft messages with expected messages received in ground stations. Key design challenges were the required small antenna size, high RF receiver sensitivity and reduced power consumption.

Architecture

The ISTsat-1's ADS-B payload comprises three main blocks: antenna, radio-frequency (RF) frontend and baseband processing including an analogue-to-digital-converter (ADC) and a multi-core microprocessor. Its architecture is depicted in Fig.1.

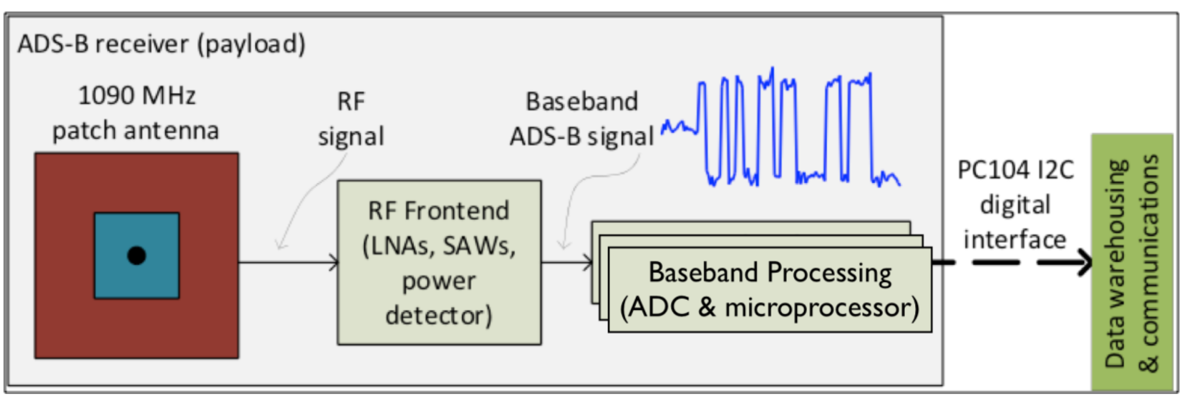

Figure 1 - Block diagram of the ISTsat-1 ADS-B receiver.

The ADS-B antenna is required to operate with circular polarization to best match the linear polarization from airplane antennas, irrespective of ISTsat-1 tumbling. Also, a compromise is required between the minimum bandwidth to minimize thermal noise pick up and the need to accommodate temperature induced band shift. The antenna configuration was otherwise mostly dictated by the 95 x 95 x 3.5 mm^3 volume available in the bottom of the cube, facing Earth. This volume precludes deployable antenna configurations.

A patch antenna with trimmed corners was selected, although the 27.5 cm wavelength still makes hard fitting it into the available volume. A high permittivity substrate DUROID 6010 (ε_r=10.2) enabled to contain the size, with slightly negative impact on efficiency. The antenna was fabricated and tested, confirming the simulated radiation pattern, polarization and impedance bandwidth. Tests included temperature cycle characterization. The 1U cube structure as well as the V/U telemetry antenna at the opposite face moderately affect the radiation pattern.

Early tests of this antenna with a commercial ADS-B receiver, on the rooftop of a 40 m tower decoded ADS-B messages up to 400 km distant planes over a mostly unobstructed SW Atlantic path.

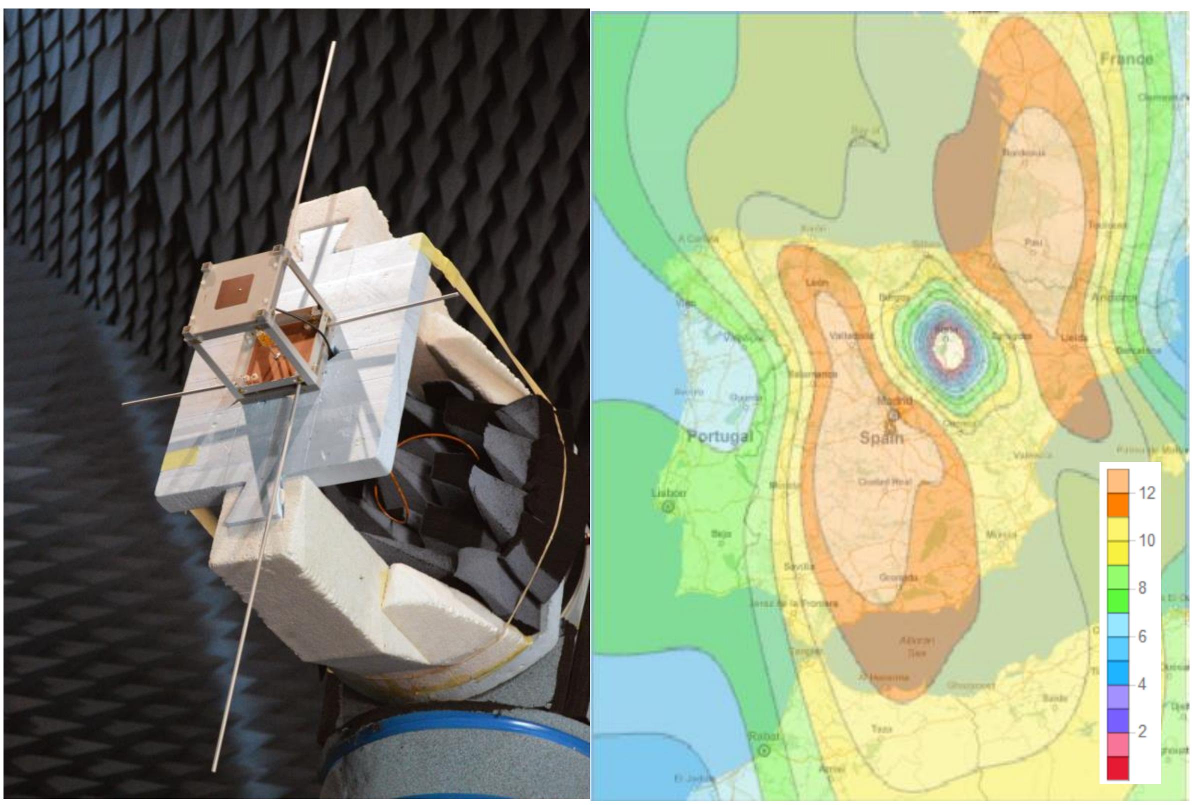

Figure 2 – a) ADS-B antenna on ISTsat-1 mockup, showing also V/U antennas. b) SNR [dB] mapped on the ground over Iberia peninsula.

The RF frontend is a tuned radio frequency non-coherent receiver. The choice of a non-coherent over a coherent topology is because: i) the signal-to-noise ratio (SNR) improvement of a binary pulse-position-modulation (BPPM) is only about 1.1 dB at a bit error rate (BER) lower than 10^{-3} [1], ii) the complexity and power consumption is much higher in a coherent receiver and iii) the coherent topology is unable to cope with the Doppler shift.

The receiver sensitivity is -95 dBm, equivalent to a SNR of 11 dB which ensures a BPPM BER of about 10^{-4}. The power detector outputs a baseband signal proportional to the RF power at its input (linear in dB). The signal bandwidth is then restricted to 2 MHz by means of a selective low pass filter and the resulting signal level is then adjusted to meet the range of the ADC which digitizes the ADS-B signal at 4 Msample/s.

An FPGA-based baseband processing was disregarded due to its typical high-power requirements. Rather, we choose a triple-core processor (LPC4370) featuring a good performance / low-power ratio.

The first core (ARM cortex M0) handles the sequence of samples, producing a bit stream in accordance with ADS-B bit encoding. This stream is then conformed to the ADS-B message format [2] (preamble and data block fields).

The second (Cortex M4) filters and processes the messages according to the specific mission parameters under evaluation. It is noteworthy that the mission requires the characterization of the Probability of Target Acquisition - PTA (ratio between the actual number of targets detected and expected number of targets to be detected within an area and time window), the Probability of Detection – POD (ratio between the actual number of received position messages and the expected number of such messages), and the Probability of Identification – POI (ratio between the actual number of received identification messages and the expected number of identification messages) [3].

The third (Cortex M0), communicating with the M4 through shared memory, interfaces the payload with the remaining ISTsat-1 subsystems, namely with the data warehousing module, for temporary storage.

The ADS-B board has been fabricated and it is under intensive testing (hardware and software). The complete version of the paper will provide experimental results showing the functionality of each block and the overall performance of the full ADS-B receiver.

[1] J. G. Proakis, Digital Communications, 2nd ed. New York, McGrawHill, 1989.
[2] Home for Mode-S and ADS-B: http://mode-s.org (*Acessed in 2018-05-02*)
[3] K. Werner, J. Bredemeyer, T. Delovski, “ADS-B over Satellite Global Air Traffic Surveillance from Space”, http://elib.dlr.de/91303/1/Final-Paper_ESAV2014-AoS.pdf