ARAMIS - Cubesat ISL Project

Abstract/Paper for S4 Symposium – Cubesat Workshop Zoom Webinar 26-29 April 2021

Col. Gerardo Petrone[1], Ten.Col.Luigi Mauro[1], CC. Gianluca Calistroni[1]
Ing.Paolo Vita[2], Ing. Giovanni Nicolai[2], Ing. Stefano Coltellacci[2]
Ing. Cesare Dionisio[3], Prof. Paolo Teofilatto[4], Ing. Stefano Carletta[4]

[1]Teledife – Italian Ministry of Defence
Via di Centocelle 301 – Rome–Italy
Direzione Informatica, Telematica e Tecnologie Avanzate (TELEDIFE) - Difesa.it

[2]Italspazio
Via Vittorio Emanuele Orlando, 7 – 95037 San Giovanni La Punta (Catania) Italy
Satellite telecommunications and communications | Italspazio

[3]SBS Space Boy Station
Via Aldo Sandulli, 45 – 00156 Rome - Italy

[4]SIA Scuola di Ingegneria Aerospaziale
Roma- Piazzale Aldo Moro,5– 00185 Rome – Italy
Scuola di ingegneria aerospaziale | Sapienza Università di Roma (uniroma1.it)

Key words: Cubesat, , Constellation, Mission, Formation, ISL, IoT, ELINT

Abstract . The ARAMIS (**A**dvanced **R**adio **A**ccess for **MI**litary**S**olutions) Phase 1 Project contract has been awarded to Italspazio (Leader of a SME Enterprises Grouping constituted by SBS and SIA) by Ministry of Italian Defence. The ARAMIS project aims to develop and verify advanced technologies which, once validated, allow Inter-Satellite Link (ISL) communication between CubeSats and between a CubeSat and the GEO satellite Athena-Fidus. The ARAMIS *Phase 1 Project* regards a feasibility study for a CubeSat constellation performing ISL. Depending on the final application, the CubeSats range from 6U to 9 U (1U=10x10x10 cm^3). The ISL operates in two bands: Q band at 42 GHz, for transmission between the CubeSats, and Ka band (31 GHz Tx and 21 GHz Rx), when a CubeSat, depending on the visibility, is connected to the GEO satellite Athena Fidus. This system can offer IoT and Elint services with polar orbits at an altitude of 500 Km.

1. ARAMIS PROJECT GENERAL DESCRIPTION

The realization of an ISL system based on CubeSat platforms imposes considerably stricter requirements, compared to those on the majority of CubeSat missions. Despite applying the most advanced design practices, most of the Components-Off-The-Shelf (COTS) based devices, typically used on CubeSat subsystems, are not compatible with the mentioned requirements. Nevertheless, the recent technological advances driven by the implementation of low-cost and high-performing CubeSats, and the rapid evolution of these systems in more complex constellations, led the rapid development of advanced on-board systems, with performances comparable to those of larger satellites. If on one hand these devices allow the realization of more sophisticated and performing platforms, on the other they imply a greater attention in the design phase, in particular in the selection of components that, even if recent, can guarantee an adequate reliability and, at the same time, avoid an increase in the cost and complexity of the whole system. In fact, a main reason for implementing CubeSat systems is that they can increase the opportunity of access to space, in virtue of their low-cost and rapid development time. This is the reason why cost related issues should be considered carefully.

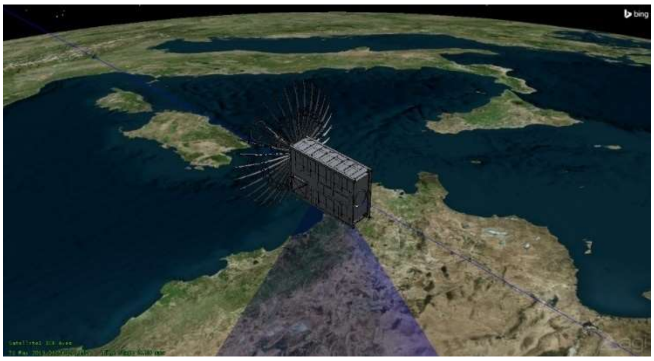

Figure 1 – ARAMIS Cubesat

2. ARAMISPROJECT GENERAL DESCRIPTION

The advanced ISL systems developed for the ARAMIS project can be useful part of several type of missions. After a tradeoff two types of missions have been selected:

- A data relay constellation of cubesats for collecting data from IoT/IoBT devices released over battlefield or an area of particular interest;
- A constellation made of triplets of cubesats to collect ELINT signals from low frequency radars. ARAMIS ISL systems can relay data about positions of these sources in short time to the ground segment.

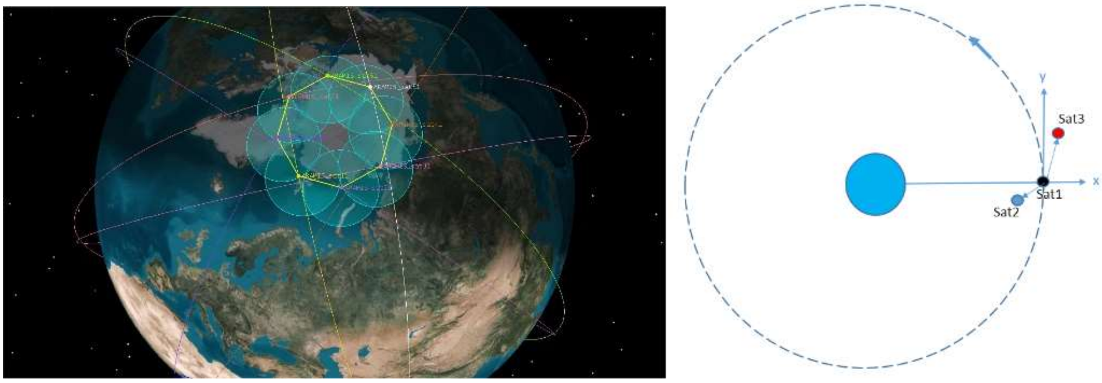

Figure 2 – ARAMIS Cubesat Constellations

3. ARAMIS MISSION ANALYSIS

To satisfy the common requirement of global coverage for ELINT and IoT/IoBT mission polar orbits were selected. The common mission philosophy includes the following aspects:

- Collect data from IoT/IoBT sensors or signals and positions of low frequency radars and store them in the internal memory of each CubeSat;
- Exchange data near the Earth poles via Q-band ISL from each CubeSat (or each triplet of CubeSats) to the others in different orbits and short distance;
- The CubeSat (or triplet of CubeSats) in the best position send data to the Data Relay Satellite in Geostationary Orbit via Ka-band hi-speed link.

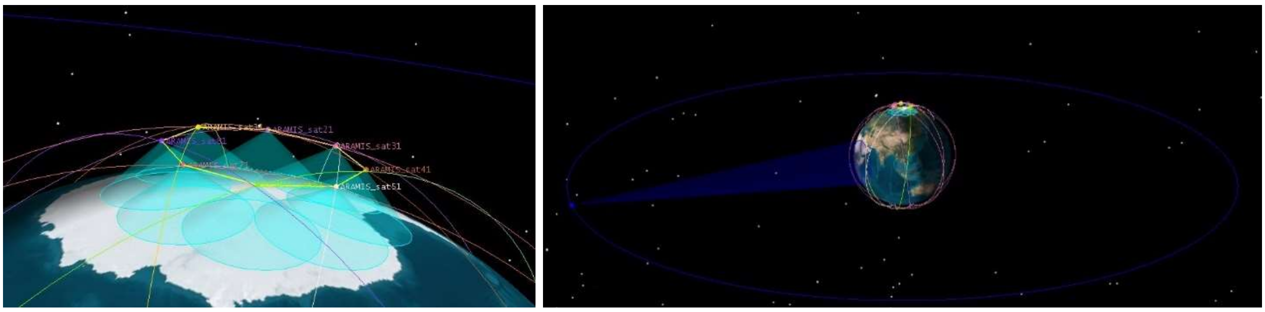

Figure 3 – Cubesat Data Exchange Philosophy and Data Transmission to Geo Satellite

The IOV/IOD mission for IoT/IoBT configuration is a reduced constellation, composed of two or three satellites, whose purpose is to validate LEO-LEO ISL and LEO-GEO Link. The IOV/IOD mission for ELINT configuration includes a single triplet of satellites, aimed at validating LEO-GEO Link and LEO-LEO ISL from each satellite of the triplet. The DRS GEO satellite can be the originally selected ITMoD satellite Athena Fidus or the future planned Ital GovSatCom satellite.
A particular regard in the ELINT mission is due to the data collection philosophy. TDOA/FDOA algorithms are used to achieve maximum precision location and accurate classification of radar signals and so a tight formation of three cubesat is used to perform this mission. Q-Band ISL synchronization between each satellite of the triplet allow better classification and scanning mode optimization

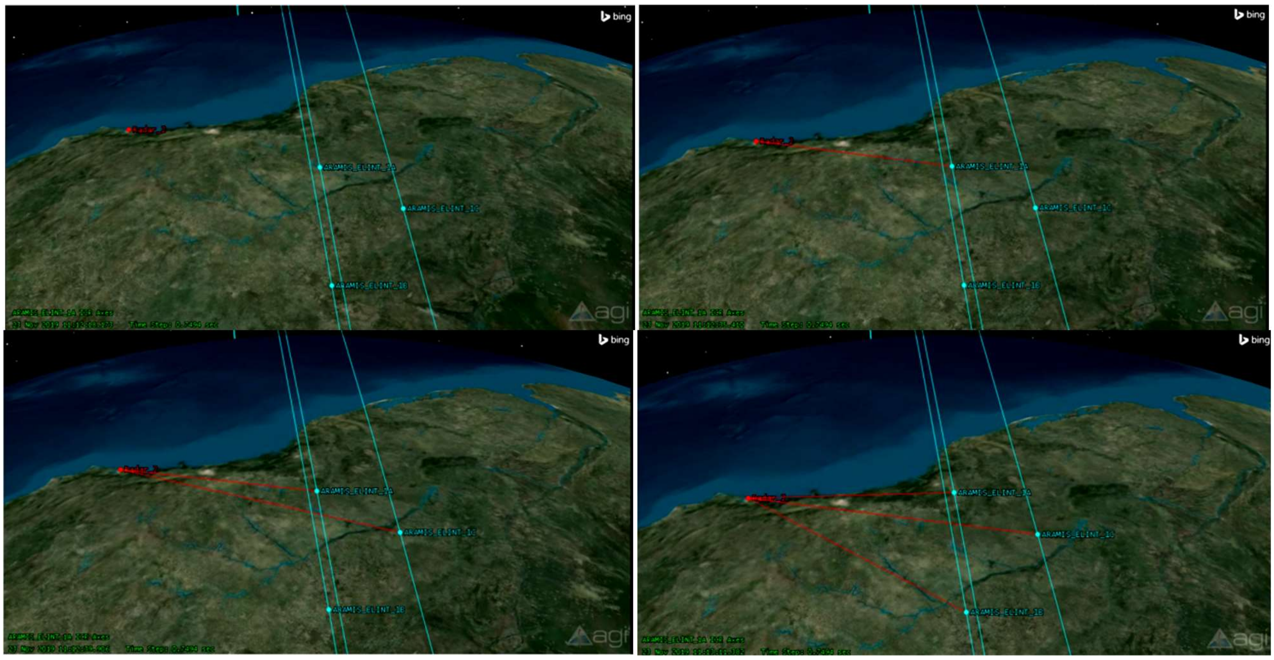

Figure 4 – ELINT mission data collect philosophy to achieve maximum precision in location of radar signals

Every triplet has an approximate altitude of 510 Km and 82° of inclination. Polar orbit allow global coverage of this system with a revisit time of 7 days for a single triplet.

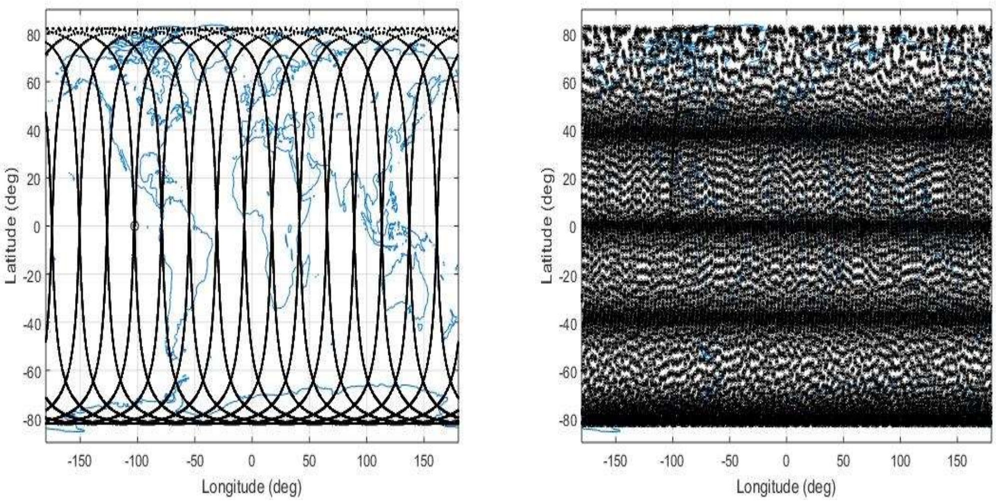

Figure 5 – ELINT mission, 1 day ground tracks (left) and 7 days ground tracks (right)

4. MAIN DEVELOPMENTS

The main developments are relevant to the following systems:

4.1 Deployable Ka Band Antenna

The reflector antenna is optimized for the Ka frequency in the Rx bands: 20.7 - 21.2 GHz and Tx: 30.7 - 31 GHz. Cassegrain reflectors, Gregorian reflectors and splash plate configurations have been identified as possible candidates. Two main constraints derive from mechanical drives.
First of all, the F / D ratio (where F is the focal length and D the diameter of the reflector) is determined by the need to minimize the curvature of the ribs so that the ribs themselves adapt between the distribution mechanism of the sub- reflector / horn and the walls of the CubeSat. For a 0.58 m reflector a minimum F / D ratio of 0.44 is determined. Secondly, the height of the sub-reflector is directly influenced by the size of the sub-reflector and by the number of mechanisms necessary to position the sub-reflector itself. To constrain the sub-reflector deployment project to feed only, the sub-reflector must be positioned at most 24 cm above the vertex. Among the possible solutions, a cassegrain type antenna configuration was chosen to meet deployment constraints. For a 0.58 m reflector with a focal length of 25.72 cm, it is not possible to use a Gregorian reflector or a splash plate since the reflector is forward with respect to the focal point. In contrast, the Cassegrain reflector optics positions the sub-reflector behind the focal point, which at this point respects the positioning required by the mechanical design with the sub-reflector within the required space of 24 cm above the vertex.

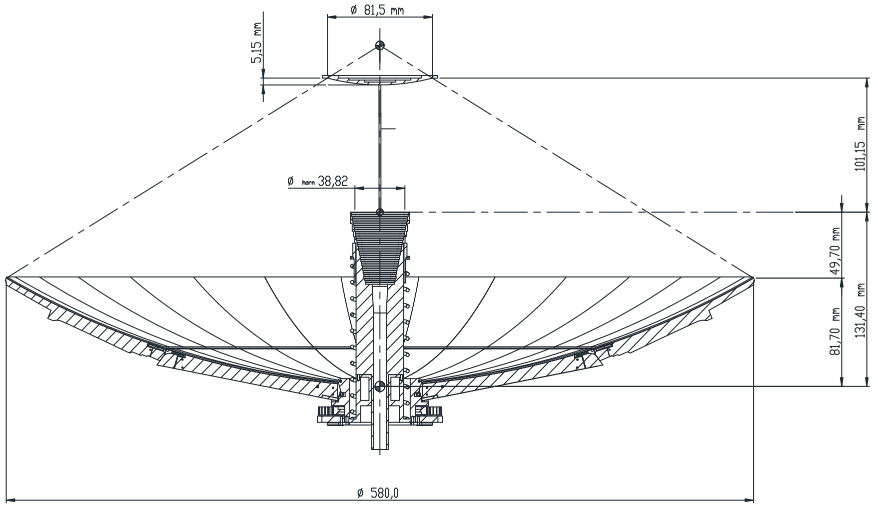

Figure 6 – Antenna Optic

The deployable Ka-band mesh reflector antenna will consist of the following main elements: The feed, three stays, a hyperbolic sub-reflector and a deployable parabolic reflector of 0.58m. The focal length is set to the minimum required 0.44 (F / D ratio) and then to 25.72 m, in order to minimize the diameter of the sub reflector to reduce the locking effect. The maximum possible directivity Dmax (D / z) 2 of the 0.58 m antenna will be: 45.21dBi at a frequency of 30.75 GHz.

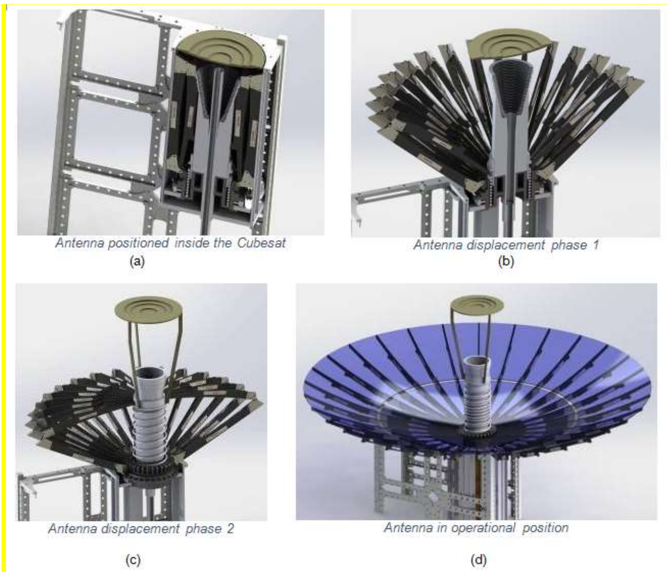

Figure 7 – Antenna deployment phases

4.2 Patch Array Q Band Antenna

The proposed layout has been designed taking into account the system specifications and also the need to obtain a circular polarization and also have impedance adaptation in correspondence with the power supply. The total size of the antenna is 4.56 x 4.56 x 0.00254 cm. The Figure 8below shows the project layout.

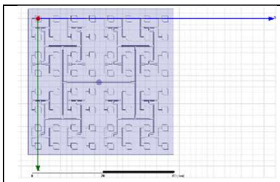	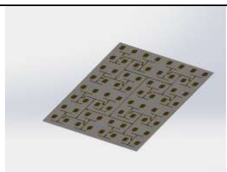	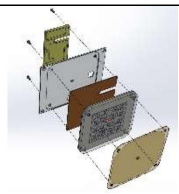
Radiation Element Layout	Board Layout	Board Mechanical Support

Figure 8 – Patch Antenna Layout

The result obtained in terms of profit complies with the technical specifications. In correspondence with we obtained a gain of 24 dBi. Also, note how the 3 dB beam opening is 10 degrees (see Figure 9).

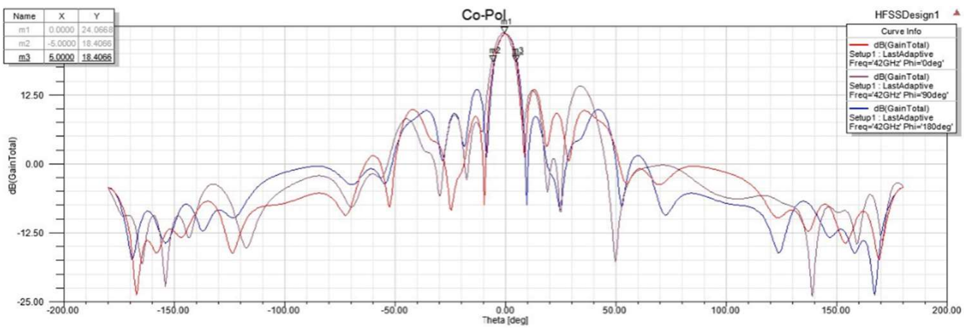

Figure 9 – Gain for the Q-band patch antenna

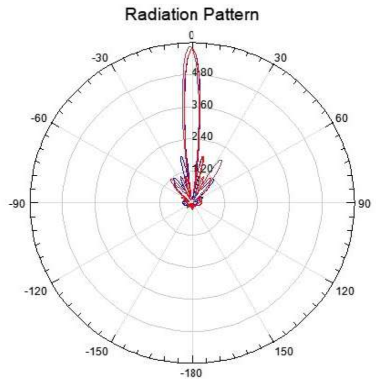

Figure 10 – Radiation pattern for the Q-band patch antenna

4.3 Q Band Inter Satellite Link (ISL) Transponder

In the following block diagrams (see Figure 11 and Figure 12), the composition chosen for the Tx and Rx chains components, related to the Q-band ISL transponder, is shown.

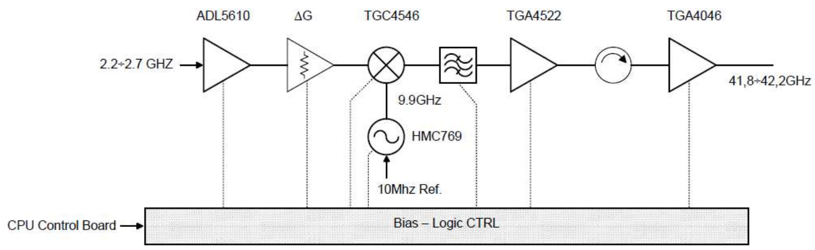

Figure 11 – SSPA and Up Converter Layout for the Tx chain

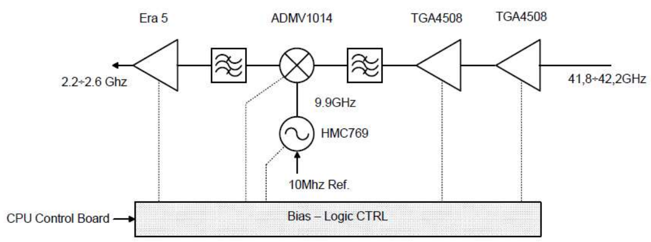

Figure 12 – LNA and Down Converter Layout for the Rx chain

4.4 Ka Band AF Communication Transponder

In the following block diagrams (see Figure 13 and Figure 14), the composition chosen for the Tx and Rx chains components, related to the Ka-band communication transponder, is shown. The components chosen are: Gain Block ADL5610, Variable gain attenuator, Mixer TGC4407-SM, Band pass filter, Gain Block HMC1131, isolator, power amplifier TGA2594, Local oscillator HMC807LP6CE.

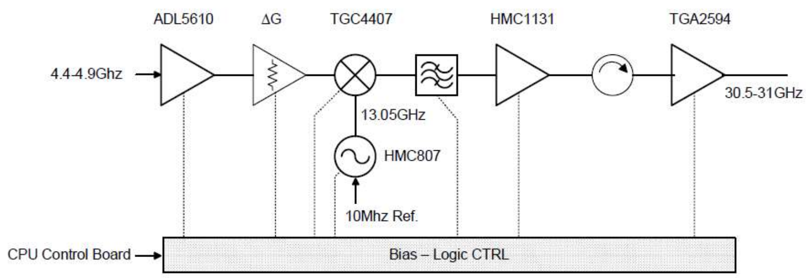

Figure 13 – SSPA and Up Converter Layout for the Tx chain

In the under-represented block diagram, the various parts that make up the Ka-band LNA & DW converter are described. The components chosen are: 2 x Gain Block ERA 5, Mixer HMC337, Band pass filter, Gain Block HMC498, Gain Block QPA2626, Local oscillator HMC769LP6CE

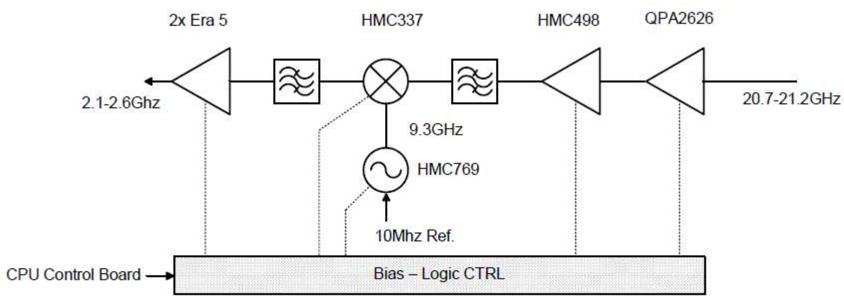

Figure 14 – LNAA and Down Converter Layout for the Rx chain

4.5 SDR Modems

The Modem will be realized in SDR-FPGA technology and making use of Open-Source libraries in particular for the algorithms of recovery of frequency, phase and symbol synchronism. The VHDL language will be used for the FPGA development phase of the functionality of the Modem.
The choice of the FPGA HW will be made between the available COTS products. The OBP processor will be selected from the available COTS products. Below is a list of COTS technologies potentially usable in the implementation of Modem.

- LMS6002D - Multi-band Multi-standard Transceiver (Limemicrosystem)
- AD9361 - RF Agile Transceiver (Analog Device)
- CMX-7164 -Multi-mode Wireless Data Modem IC (CML Microcircuits)
- SX-3000 Ultra-Wideband SDR Modem SoC (SatixFy)

4.6 IoT Application Payload

The ARAMIS IoT payload will be based on a very flexible SDR design such to cope with many of the current standards operating in the UHF bandwidth (400-3000 MHz) . In particular the LoRa-E is specifically focused for its capability to operate at very low S/N so allowing long resilience, low detectability and low power consumption of the batteries of the ground terminals.
A UHF deployable antenna with 6 dBi gain will gather the ground data while the implementation of a S band transmitter may be a good option for commanding the ground terminals. The SDR receiver based on COTS and FPGA can be programmed to operate even for other applications if requested. The gathered data are stored in the cubesat mass memory to be sent via the ISL's to the ground station after formatting and encryption.

4.7 ELINT Application Payload

The ELINT application payload operates by a TDOA/FDOA approach based on a formation of three satellites each embarking a wide BW signal acquisition payload. The payload includes two wide BW deployable antennas followed by innovative receiver chains. The data are then transmitted to ground via GEO ISL when inside the Athena Fidus coverage. The formation configuration sees two satellites on the same orbit plan and a third flying around. Relative positions are computed by processing powerful EGNSS receivers' observables. The data processing and on ground source location and analysis is done on ground in the processing center.

5. ARAMIS CUBESAT LAYOUTS

In case of an IoT mission, it is possible to integrate the Aramis Cubesatsatellite into a 6U units, respecting the volume, mass and power requirements. All the main functions (the commands to be sent in the various operations, the on-board registration, data transmission and power management on board) will be assumed by OBC (On Board Computer) and by the Electrical Power Subsystem (EPS). Satellite balanceand flight dynamics will be also important, especially in case of incorporating an orbital control system.The following Figure 15 gives an idea of how the Aramis Cubesatcould be realized and how the subsystems could be arranged within it.

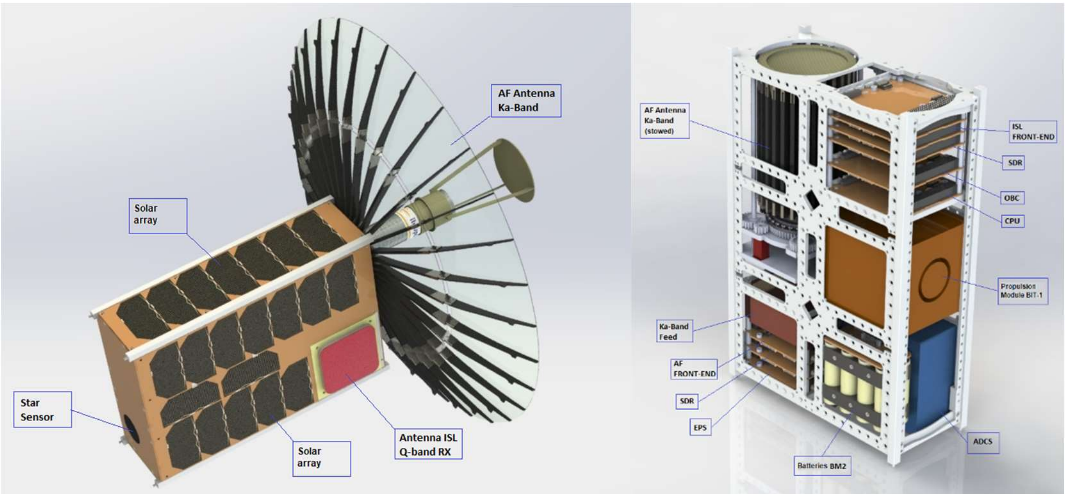

Figure 15 – ARAMIS Cubesat Layout for IoT Mission

If the ELINT mission could be applied, the minimum dimension of the Aramis Cubesat will be 9U as shown in Figure 16.

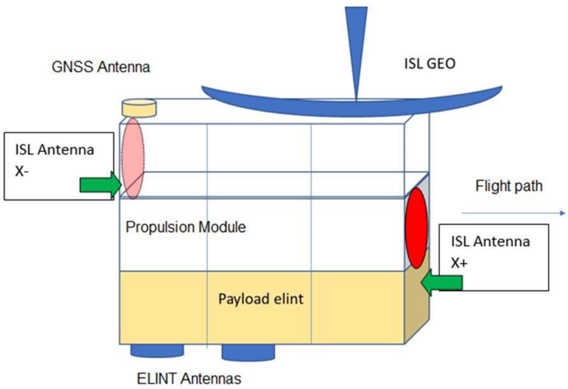

Figure 16 – ARAMIS Cubesat Layout for ELINT Mission