A Game-changing radio communication architecture for cube/nano satellites

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ABSTRACT

Technological improvements achieved since 15 years allowed nanosatellites to emerge. 3U and bigger Cubesats permit functions and reliability once specific to microsatellites. The RF game-changing is related to higher frequencies and data rates.

Following the in-orbit X-band High Data Rate TeleMetry success on board the ESA Proba-V microsatellite, Syrlinks has finalized with CNES and ESA the development of a new solution to download payload telemetry in X-Band at high data rate for smaller platforms, such as Nanosatellites and CubeSats. This equipment is able to modulate data up to 100 Mbps using fully CCSDS compatible filtered OQPSK modulation and Convolutional Coding [7,1/2]. It delivers up to 2 Watts RF with no more than up to 10W DC/DC consumption, and fits inside a 0.25 Unit of a standard cubesat. . This miniature X band HDR-TM transmitter is planned to be used on board OPS-SAT, an ESA triple Cubesat dedicated to test new space operation control concepts, currently planned for launch in 2017. It is also planed to be used on board EYE-SAT, a Student/CNES triplecubsat, also in 2017. More rescently, a decision was taken to test this equipement on board the GOMX-3 triple cubesat in the frame of an ESA project, as soon as till the autumn 2015.

In parallel, answering customer requirements, Syrlinks is also developing with CNES a new S -

band transceiver which is fully compliant with CCSDS recommendations for RF, Modulation and Coding, and therefore with ITU EESS frequency bands for TT&C. The transmitter can provide data rates up to 3Mbps (OQPSK with differential coding) with an adjustable output power from 27 to 33 dBm. The receiver supports data rates from 8 to 256 kbps (PCM/PM/SP-L). This integrated product fits inside a 0.25 Unitwhen no diplexer is used. It is a miniaturized version of an existing Syrlinks platform. In 2014, an EQM has been developed and evaluation tests are also on-going. This miniature S-band transceiver is also planned to be used on board OPS-SAT and EYE-SAT, and will satisfy the requirement that the cubesat will look like a fully CCSDS compliant spacecraft to the ESA and CNES ground control segments. The RF system on-board architecture of OPS-SAT andEYE-SAT, describing the S-band TT&C and X-band HDR-TM is presented.

This paper provides information on these CCSDS compliant RF products, and the RF architecture used to implement them on board OPS-SAT, EYE-SAT and GOMX-3. Using these products would not only guarantee a correct use of the allocated frequencies, but also ease the possibility to re-use “standard” CCSDS compatible satellite ground stations for Nano/CubeSat missions.

Keywords: RadioFrequency, cubesat, OPS-SAT, EYE-SAT, GOMX-3, TT&C, S-band, TM, X-band, CCSDS, telecommand, telemetry, nanosat

1. Introduction

The space agencies are equipped with networks of tracking ground stations compatible with ITU and CCSDS (Consultative Committee for Space Data Systems) standards [1], [2], [3] . These networks use Earth Exploration Satellite System (EESS) TT&C S-band (2025-2100 MHz for TeleCommand; 2200-2290 for TeleMetry), and X-band (8025-8400 MHz for High Data Rate-TeleMetry). More and more private ground tracking networks are also equipped with S+X ground stations, benefiting from a station cost reduction trend.

CubeSats are presently generally fitted with UHF or S band payload TM subsystems which allow downloading a few hundreds of Mbits per day. This data volume is limited because the telemetry bit rates are restricted to hundred of kbps in UHF and to few Mbps in S band to comply with the CCSDS spectral recommended occupation bandwidth (6 MHz maximum in EESS S-band). The use of a fraction of the ISM S-band (2400-2483.5 MHz) is also possible for telemetry, but this band is very subject to interferences, and is not associated to an ISM S-band for TC to allow a single S band TT&C equipment. To limit the number of antenna and equipments on board and to increase the TeleCommanding capacity (for software upload for instance), EESS S-band TCs looks appropriate.

Therefore, to increase transmission data rates and to allow compatibility with their existing ground tracking networks, CNES and ESA are interested in a miniature S-band TT&C transceiver, and in a miniature X-band transmitter, both designed for cubsats. ESA decided to design the OPS-SAT triple CubeSat to test new space operation control concepts using EES S and X bands. The launch of OPS-SAT is planned for 2017.

Today, earth observation or spectrum monitoring or astronomy or technological payloads can be embarked on very small platforms but they require the capability to download a large volume of data with a high telemetry bit rate subsystem. The Syrlinks’ EWC27 HDR-TM X-band transmitter combined with a miniaturized COTS antenna solves this problem and enables to download up to 17 GB per day on a 3.4 m X-band station. CNES and Students are currently developing the EYE-SAT triple CubeSat, provided with an astronomical payload to observe zodialcal light. The needs in term of data rate imposed the use of EWC27 X-band HDR-TM.

In order to allow early in-orbit testing of the EWC27 HDR-TM as soon as the automn 2015, CNES and ESA cofunded the end of the qualification process of this equipement, and its integration in the GOMX-3 ESA triple CubeSat.

The paper presents the key elements which have been taken into account to design the S-band micro TT&C transceiver and the X-band micro HDR-TM transmitter, and provides the main features of this equipment. The paper also describes OPS-SAT, the student/CNES EYE-SAT triple CubeSats, and GOMX-3. The way these satellites use the Syrlinks micro RF equipment is also presented.

2. S-band system architecture

CubeSats which are considered here are fully operated from S-band tracking ground networks, like ESA or CNES ones. Of course it is not incompatible with additional or specific-only dedicated S-band (or S+X) ground stations. This enables to remove, in operational cubesats, the VHF/UHF subsystem which also presents the inconvenience to be more and more subject to

interferences. Such a choice has been made for EYE-SAT.
The Syrlinks EWC31 TT&C transceiver currently under ending development has a CubeSat form factor with a height of about 4 cm including the diplexer and 3 dB coupler when needed (its high is about 2.5 cm without diplexer). Operational CubeSats might need such a diplexer, in order to connect two S-band patch Rx/Tx antennas mounted on opposite faces to the transceiver, through a 3 dB coupler. Doing so, whatever the CubeSat's attitude in orbit, there will be always one of the 2 antennas pointing roughly toward the ground.Therefore such subsystem allows permanent TC and TM connections with the involved 2 GHz tracking ground station(s), even if the satellite is temporary subject to uncontrolled tumbling for instance.
The two S-band Rx/Tx patch antennas shall be provided with a single RF connector, used to input and output S-band TC and TM signals. If, as it is generally the case, the using space agency ground network is provided with dual circular polarization parabolic antennas, the two patch antennas mounted on opposite faces of the CubeSat can have opposite circular polarization, to minimize the coupling between these 2 patches, and to facilitate the ground S-band tracking operations. This can be done especially if the tumbling angular velocities are not high. If not, when only single polarisation ground stations are available, of when the maximum tumbling angular velocities to cope with are very high, to use the same polarisation on the two patch on-board S antenna should be possible, but, in all cases, a carefull global antenna pattern measurement provided by the two patch antennas mounted on a structure representative of the CubeSat is mendatory.
The choices of modulation and coding have a major impact on the S-band subsystems performances regarding the bit rate, consumption, implementation complexity, but also the interoperability possibilities with the ground segment.
This S-band subsystem's architecture will be used by the OPS-SAT tripleCubeSat of ESA, described in previous sections. One specific version might be also used by the MEDITERANNEE-SAT (Robusta-3A) Student/CNES tripleCubSat. In both cases, these satellites will use a back-up UHF(/VHF) TT&C.

3. X-band system architecture

Existing Nanosat telemetry systems (UHF or S band) can dump only a few hundred of Mb to 1 Gb per pass. Emerging need for higher dumping capacity on CubeSat made a new solution (the X Band Transmitter) emerge to provide a major improvement (for instance 6 Gbs to 14 Gbs per pass), compatible with X band stations (3.4 m to 5 m diameter in that case), and affordable in the nanosat format (3U): power consumption below 10 W peak , 1W mean/orbit, 300g, small antenna. The Transmitter RF output power can be tuned up to 2 W (assuming 10 W peak consumption and 10% duty cycle). The telemetry antenna's gain is assumed to be 0 dBi at +/- 60°, with 1 dB antenna loss, this giving an EIRP of 2 dBW. The Ground station can have for instance a diameter of 3.4 m (25 dB/K G/T) : above 10° elevation, or 5 m (30 dB/K G/T) : above 5° elevation.
The modulation and coding currently choosen are a power efficient standard rather than spectrum efficient (as required for larger bit rate) , to benefit from a 4 to 5 dB impact. This standard is compatible with usual ground stations and CCSDS: OQPSK with Convolutionnal Coding (k=7, R= ½ + 255/223 Reed Solomon).
Outside its RF performances, OQPSK with k=7 R=½ + RS is also very interesting because Convolutional and Reed Solomon coding operations can be split and performed in different locations. The first one can easily be implemented into the transmitter and realized in real time. The second one can be performed with the framing at the mass memory or processor level in real time or by post processing. Such repartition also facilitates the interface between the mass memory or processor and the transmitter because the dataflow to modulate is continuous.
Using Constant Bit Rate (CBR), large and unexploited link budget margins occur at elevations higher than 20°. Using Variable Bit rate (VBR) with Nbr possible values of bit rates, the download capacity is multiplied by 1.6 with Nbr=2, and multiplied by 2 with Nbr=3 during a pass. During the bit rate change transition sequences, IDLE sequences are used to avoid data losses. The transition time percentage during the pass is estimated to 5% with 3 bit rates (5 s / commutation). The ground station receiver could receive predictable commands to stations for bit rate switching, if not autonomous.

VBR with OQPSK and k=7, R= ½ convolutional + RS codings is CCSDS compatible, despite the signal spectrum variation during a pass, since CCSDS defines the "mission phases" as the mission period during which the signal parameters are constant. That means that a pass using VBR is provided with N+1 "mission phases", when there is N bit rate commutations, with N = 2*(Nbr-1). With a maximum bit rate of 50 Mbits/s, the maximum spectral width of the transmitted telemetry signal is significantly smaller than the 375 MHz available in the EESS X-band.

4. EWC31 S-band TT&C Transceiver, product key elements

EWC31 S-band TT&C transceiver takes some results from a pluriannual CNES R&D program related to low cost basebricks for TT&C, in term of flexible power amplifiers (*with an optimized efficiency at the different RF powers*), high performance synthetiser and modem, and high integration of the TT&C functions. [4], [5].
The system architecture of this new product is generic. It was tested and fully validated on a first breadboard. All the key base-band functions are implemented in an FPGA. So this platform can be also easily adapted and provides the possibility to cover specific needs for new missions.

The main transceiver specifications are:

<u>For the Transmitter:</u>

- Frequency band: 2200-2290 MHz
- RF Power from 27 to 33 dBm
- Data Rate: One fixed rate from 10 kbps to 3 Mbps
- Modulation: QPSK/OQPSK
- Convolutional Coding (7;1/2)
- Consumption (to be confirmed on EQM) :
    - <9.0W for 2W RF output
    - <6.5W for 1W RF output
    - <5W for 0.5W RF output

<u>For the Receiver:</u>

- Frequency band: 2025-2110 MHz
- Modulation: PCM/SP-L/PM
- Data Rate: One fixed rate selectable between at least 8, 16, 32, 64, 128, 256 kbps. Data rates lower than 8 kbps remain to be validated.
- Doppler: +/-66kHz (@1,8 kHz/s)

Some optimizations were made to provide a highly integrated solution with the following external dimensions (without diplexer) of: 96 x 90 x 24 mm^3

Figure 1 : EWC31 S band TT&C/ISL with 1 first diplexer configuration and integrated coupler

The functional evaluation of EQM are on-going. The product's performances are tested in temperature and at different input voltages.

Another key sub-system is highly critical in this TTC function, the diplexer. A system analysis was made to balance the transceiver's performances (TX and RX) with the diplexer's size. Moreover, the specificities using one or two antennas on the CubeSat platform was addressed and optimized solutions are available for these two configurations (Fig 1, Fig 2).

The coherent transponder option is beeing currently in development for the microsat S band TT&C equipment of Syrlinks, thanks to activities for ESA and CNES, the functionalities enabling ground stations to perfom coherent Doppler and/or ranging measurements could be implemented in EWC31 advanced TT&C S-band equipment.

Figure 2 : EWC31 S band TT&C/ISL with a second diplexer configuration and integrated copler

After the last functional validation, some qualification tests (as Mechanical tests, Temperature cycling, Cumulated dose, Life Test, ON/OFF Cycles, …) will be made in Q3 2015 on some Qualification Models. This Product Qualification principle was developed with CNES on Syrlinks first generation of S-band TTC transceivers for the Myriad platform. This method was also used during the environmental qualification of Syrlinks X-band transmitter developed for ESA Proba-V mission, and for the EWC27 X band transmitter before its first in-flight test planed on board GOMX-3. After that qualification period, the delivery of Flight Models is possible within 4 to 6 months depending upon selected options. New studied options are also the 2.4 GHz TT&C configuration, and the ISL/proximity link configuration, itself with an integrated ranging option. The ISL/proximity link configuration will allow for instance an orbiter to perform ranging measurements related to a lander on an asteroïd, a comet, or the lunar surface, or between 2 earth orbiting spacecrafts in LEO or HEO. New missions of that kind are studying the use of the EWC31 S-band TT&C transponders, after the use of the previous generation of Syrlinks S-band equipment on board Deep-Impact NASA mission to explore the comet Tempel in 2005, and the ESA/CNES/DLR Rosetta-Philae mission.

5. EWC27 X-band HDR-TM transmitter key elements

Some presentations of Syrlinks EWC27 X band transmitter were made in some Conferences [6], [7].

The key specifications of this product are :

- Useful data rate from 2.8 up to 50 Mbps with Variable Bit Rate (up to 100 Mbps in Constant Bit Rate)·
- Configurable data rate (in flight up to 50 Mbps)·
- Convolutive data coding: Puncturing rate ½, constraint length 7, polynomial generators 171 and 133.
- Offset-QPSK modulation·
- High-efficiency power amplifier·
- Flexible RF output power between 27 – 33dBm, with 1-dB step·
- Power consumption·
    - <7 W for 1W RF output power·
    - < 10W for 2W RF output power

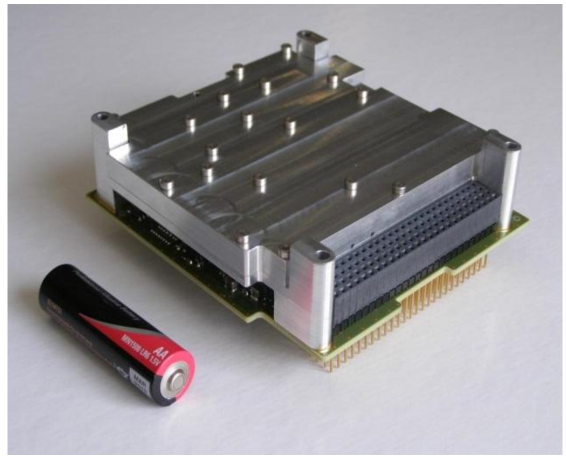


Figure 3 : EWC27 X-Band HDR-TM transmitter

The mechanical integration was optimized in order to fit into the following external dimensions[1] : 96 x 90 x 24 mm^3. The functional validation of EWC27 EQM is completed. This phase has been followed by an environmental qualification phase completed in june 2015. FM delivery time is also for this X-band transmitter 4 to 6 months.

EWC27 can provide up to 50 Mbits/s using VBR, or up to 100 Mbits/s using CBR/CCM. For this reason, it covers more or less the performances presently offered in Ka band for nanosats, but for a lower global complexity.

Syrlinks and CNES are currently studying a version of the EWC27 X-band HDR-TM compatible with some mod-cods of the CCSDS DVB-S2 telemetry standard.

6. The OPS-SAT mission

OPS-SAT is an ESA nanosatellite mission designed exclusively to demonstrate ground-breaking satellite and ground control software under real flight conditions. The project is being led by the European Space Operations Centre (ESOC) in Germany. Following a successful ESA Concurrent Design Facility (CDF) study early in 2012, the project kicked off with two parallel Phase AB1 studies in July 2013. These were led by TU Graz of Austria and GomSpace of Denmark respectively. Phase B/C/D/E started officially in february 2015 and the satellite will be ready to launch in 2017. TU-Graz is now leading a consortium for Phase B/C/D/E. Core avionics will be delivered by GomSpace.

One of the major requirements of the mission is that at least one configuration shall be representative of an ESA mission (including ground to space interfaces). In simple terms, OPS-SAT has to look like a real ESA satellite to the ground and be compatible with the ESTRACK ground station network. During the CDF this requirement was identified as a major challenge due to the lack of a CubeSat sized CCSDS compatible S band transceiver on the market. The solution proposed was to mechanically modify an existing S band transceiver to try to squeeze it into the cubesat form factor. The solution was declared feasible but with a diplexer it took up around half of the available volume of the satellite. The CDF declared that "All the requirements can be matched with presented design but two options have been identified with the intention of reducing onboard resources requested by the communication subsystem and are as follows:

1. Development of a dedicated miniaturized Transponder/Transceiver with low power consumption RX as driver.
2. Development of a miniaturized Diplexer: solution based on dual port antenna can be of interest."

The identification of the new EWC31 S-band transceiver from Syrlinks by the TU Graz led team in Phase A/B1 has led to significant advantages for the mission as a whole. The 60% reduction in volume and power usage achieved in the new design has been exploited to remove the single point failures in the CDF design and to drastically improve the capabilities of the payload. In turn this has allowed significantly more of the proposed experiments for the mission to be accepted.

Another fundamental OPS-SAT mission requirement is to be able to change the complete on-board software on a daily basis. This has led to the system requirement that uplink rates of a minimum 256 kbps are required. This is way above the highest uplink rate for normal ESA spacecraft which is 4 kbps rising to a maximum of 64 kbps in some rare cases. This requirement is already driving innovation on the ESA ground segment and presents us with a prime example of the nanosatellite world challenging long standing and accepted limitations in the world of big space. This high uplink date rate is supported by the transceiver.

Finally, the mission requires that the ground can communicate with the satellite via S band in any attitude. In fact, to minimize the amount of critical software, when OPS-SAT enters safe mode then the fine pointing attitude control system is switched off. The spacecraft relies on solar panels being placed on most faces and a robust, passive thermal design to survive rather than going to any particular set attitude. Hence it is clear that the EWC31 S band transceiver must serve two receive/transmit antennas (one on each side of the spacecraft) to provide the necessary quasi Omni-directional coverage.

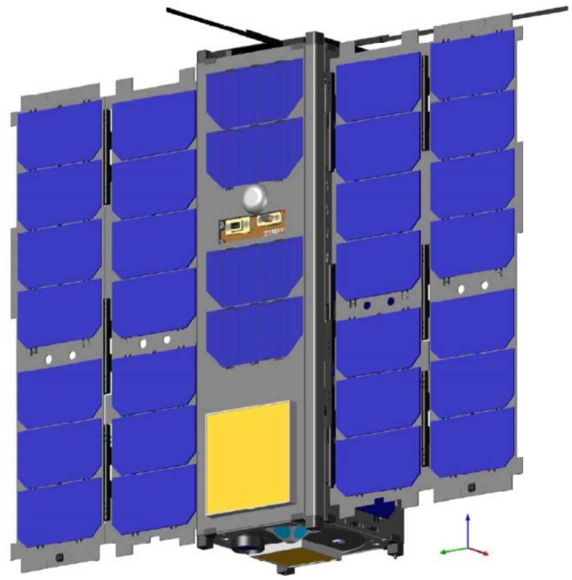


Figure 4 : OPS-SAT showing S band patch antenna (yellow) and the X-band antenna on the Z face antenna (Nadir Pointing)

If the EWC31 S band transceiver was important in the latter parts of the core mission, the miniature EWC27 X band HDR-TM transmitter was highly relevant in defining the OPS-SAT mission in the first place. CNES contacted ESA/ESOC with the idea of flying such a transmitter on-board a CubeSat in 2011. Further discussions led to the conclusion that the required technology to fly CCSDS compatible transponders on nanosatellites (even given the constraints on mass, power and volume) was on the verge of being available. This directly led to the concept of OPS-SAT being studied in the CDF and the EWC27 X band transmitter experiment was used to generate requirements for the platform design.

In Phase AB1 the HDR-TM was included as a payload of opportunity i.e. to be considered once the margins left for such payloads were clear. It was subsequently selected to fly because it has a great deal of synergy with the other experiments (some want to download large amounts of data e.g. video). This would only be possible via a X band or higher frequency transmitter.

OPS-SAT will be a “laboratory in the sky”. The core is a system on-chip module (Altera Cyclone-V) with dual ARM-9 processors and an FPGA allowing software and hardware reconfigurability for the experimenters. During an Open Call by ESA in 2013 more than 100 experiments were proposed, the majority being software experiments.). 91 % of the experiments are feasible on OPS-SAT. To allow the fast upload of software images, the S-band transmitters must be able to uplink at 256 kbit/s. The UHF transceiver on the CubeSat bus can only support data rates of 9.6 kbit/s and is not suitable for the transferof large software images. On the other hand, some experiments will generate substantial data volumes, e.g. when high-resolution images are taken. In this case the relatively high data rate of the S-band transmitter is beneficial.
OPS-SAT will also carry a camera with an estimated ground resolution of approximately 60 m. On-board image processing has been proposed This camera will support both still image and streaming video modes. In the latter case, a high downlink data rate is required. Such camera experiments will require substantial downlink data rates for which the EWC27 X-band transmitter will be needed, particularly when bearing in mind real-time applications and the short contact times (typically 10 minutes for a ground station pass).
The S and X Band antennas for OPS-SAT were designed by TU Graz. The engineering models are currently undergoing subsystem tests.

7. The EYE-SAT mission

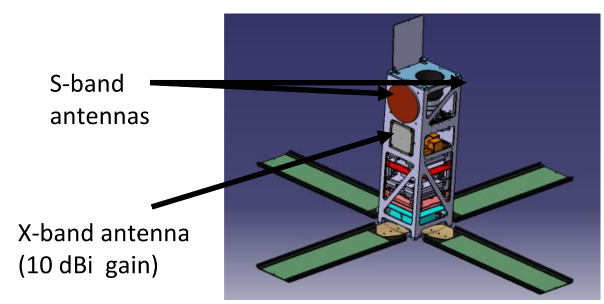
JANUS (‘Jeunes en Apprentissage pour la réalisation de Nanosatellites au sein des Universités et des écoles de l’enseignement Supérieur’) is a CNES project which helps students, by both financial and technical supports, to make their own nanosatellite. Twelve projects are ongoing and four of them are involved in the Van Karman Institute’s QB50 project [12]. In that context, EYE-SAT is a triple CubeSat being developed by students from engineering schools working at CNES in Toulouse, together with students from a University Technological Institute (IUT) in Cachan, France.

To be launched in 2017, EYE-SAT will evolve on a Sun-synchronous orbit at 700 km for one year and has three objectives to complete. The main goal is to observe the zodiacal light which is a faint glow resulting from sun light scattered by interplanetary dust particles. Reviews about the zodiacal light, including the significance of its study, its intensity and polarization, and its properties can be found in [8], [9], [10]. The second objective is to provide a 360° colored picture of the Milky Way for the project outreach. The last goal of EYE-SAT is to make use of state-of-the-art technologies to both accomplish the mission and demonstrate them.
EYE-SAT will measure the zodiacal light intensity into four spectral bands – red, blue, green and near infrared – for three different polarization angles – 0°, 60° and 120°. Thus, light intensity and linear polarization regarding the spectral domain will be obtained. EYE-SAT’s payload, called IRIS (Imager Realized for Interplanetary Dust Study), is a 13°x13° field of view imager with a focal length of 50 mm. Two wheels will accommodate spectral and polarizing filters respectively.

This particular mission was chosen to make a 3U CubeSat as efficient as possible. Indeed an astronomy mission leads to harsh system requirements. For instance imaging the zodiacal light and the Milky Way needs a 3-axis attitude control with a 0.25° pointing accuracy and 0.02°/s stability. The communication system has to be efficient as well. About 15 Gbits will be produced every day so Eye-Sat integrates the EWC27 X-Band HDR-TM transmitter connected to a directive antenna with an axis gain of 10 dBi using a CNES home made antenna. As a result Eye-Sat should reach data rates of 28 Mbits/s permanently during pass, thanks to a ground station pointing mode of the satellite, and to a ground station in Toulouse provided with 3.4 meter antenna

In 2014, CNES selected a single S/S + X band RF architecture for EYE-SAT. Two patch “omni” antennas under development will be used.

In addition to the EWC27 X-Band HDR-TM transmitter, several technologies are embedded to be demonstrated. The on-board computer is based on an ARM Cortex A9 microprocessor and one FPGA; and supports embedded software based on time and space partitioning architecture. IRIS integrates a three-color CMOS detector instead of a classical CCD technology. Finally the solar panels will be deployed thanks to self-deployable and self-blocking composite hinges.



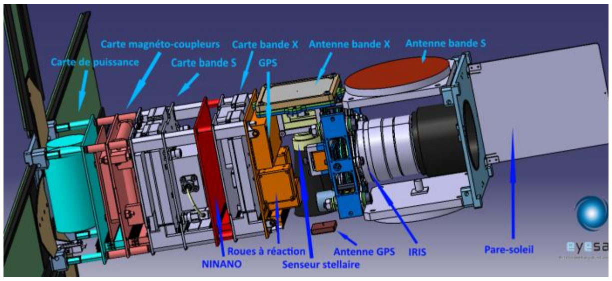


Figure 5 : Views of Eye-Sat (with EWC31 and EWC27 equipments and antennas)

After a successfully completed phase A, phase B started on September 2013. A structural model has been built, an engineering model and an instrument mock-up are under construction. Phase C and D will be realized from November 2015 to November 2016. Two flight models will be made, one for qualification and the other for the flight. Final objective is to be ready for the launch in April 2017.

7. The GOMX-3 mission

GOMX-3 is the inaugural ESA In-Orbit DemonstrationCubeSat, led by GomSpace, and funded under the General Support Technology Programme. It will achieve pointing within 2° of both nadir and geostationary targets will demonstrate aircraft ADS-B signal reception and characterize geostationary telecommunication satellite spot beam signal quality. The satellite is scheduled to launch during the HTV-5 mission in August 2015. Danish astronaut Andreas Mogensen will deploy the satellite during his stay at the ISS in September 2015.

The satellite was developed, integrated, tested, and delivered over a period of 13 months using off the shelf components available from GomSpace. GOMX-3 uses the next generation of CubeSat OBC (NanoMind A3200) and UHF radio (NanoCom AX100). Both of these subsystems use a motherboard-daughterboard system designed to minimize stack height to fit more capability in a smaller volume. A P31us EPS and a BP4 battery pack complete the CubeSat bus.

Pointing is key to the GOMX-3 mission; the satellite uses a combination of advanced sensors (coarse sun sensors, IR horizon sensors, magnetometers, fine sun sensors, NovAtel GPS receiver) and actuators (in-panel magnetorquers, Astrofein momentum wheels) controlled by a dedicated ADCS A3200 computer. The GomSpace ADS-B receiver, a GomSpace software-defined radio module, and the Syrlinks EWC27 CubeSat X-band transmitter complete the internal payload stack.

Figure 6 : The GOMX-3 satellite

The first in-orbit test of the Syrlinks EWC27 X-band transmitter will occur aboard GOMX-3. Syrlinks developed an X-band patch antenna considering the following initial requirements: Frequency band between 8.025 and 8.4GHz, RHCP polarization, <3dB axial ratio, <3dB between -/+30°, >0dBi Gain between -/+30° from boresight, <12dB return loss in 400MHz bandwidth. The available volume on the GOMX-3 platform for the antenna was limited, especially the thickness was restricted to 7 mm. The as-built dimensions of the active part of the antenna are 73.5 x 73.5 m x 6.8 mm. The measured performances are in line with simulations results. Finally some qualification tests (temperature cycling, vibration, thermal vacuum) were made in order to check the evolution of the peformances after environmental testing.

CNES also participated in the GOMX-3 project by providing two X-band ground stations. The first station is new and is located at the French Guyana Space Center (CSG), in Kourou, and will be used for experimental passes till end 2015. It has an antenna diameter of 11 meters. The second one is a quite “old” 3 CNES X-band station provided with a 3.4 meter antenna, and has been transferred from the Operation directorate to the JANUS Student/CNES nanosat project. It is now physically implemented at the site of ENAC, the French national civil aviation engineering school, and presently being refurbished. It will be used in a second step, after the test period with the station in Kourou.

7. Conclusion

The UHF/VHF or UHF Cubesat TTC subsystem still used today is increasingly subject to RF interferences as the frequency set is shared with ground and space telecommunications. Moreover UHF/VHF bands are very occupied and subject to other interfering RF transmissions. Another drawback is the data rate limitation, poorly suited to software uploads and accurate platform monitoring.

In parallel, more CubeSat missions need some tens of MBits/s to download HD imaging or collected RF signals for ground processing center analysis. EESS S-band Telemetry is sometimes used for such downloads, but ITU filing could generally be obtained if the recommendation to use 6 MHz as a maximum was fulfilled. The 2.4 - 2.4835 GHz band is sometimes used for higher telemetry datarate but its ISM nature make it subject to potentially significant interference issues.

Therefore, a combined S/S+X band architecture is able to deliver datarate increase. Both EESS S TTC and X bands look well adapted, since very few interferences have been monitored by CNES ground stations network in these bands. EYE-SAT and GOMX-3 triplecubesats totally or partially implement this architecture.

Syrlinks works jointly with CNES, ESA, TU Graz, and GomSpace to develop advanced radio solutions for CubeSats. Syrlinks proposes cubesat RF equipments using EESS X band, or EESS or ISM S band, or both S and X band (fig. 7), and study also solution using other bands. The EWC27 X band transmitter reuses an important part of the ESA Proba-V telemetry hardware, and provides up to 100 Mbps. The EWC31 S Band equipment is also fully CCSDS compatible with ranging and coherent transmission capabilities.

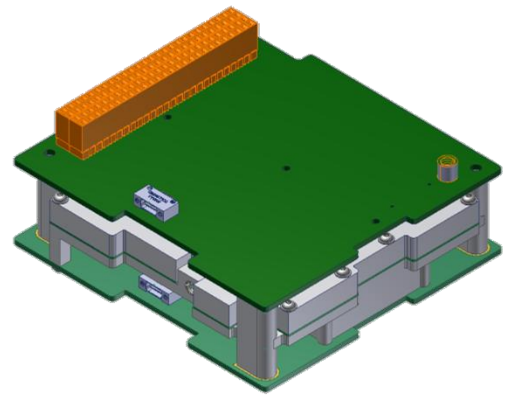


Figure 7 : 3D Modeling of EWC27 X Band Transmitter from Syrlinks, integrating S band Receiver (extracted from EWC31 S TT&C Transceiver from Syrlinks)

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