Sysnova Weather Challenge Response: Executive Summary

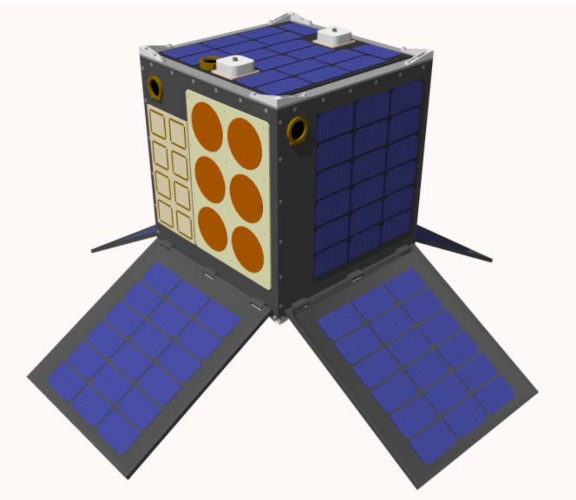

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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There is a need to achieve optimal cost effectiveness from remote sensing missions. Concurrently, a key scientific need in remote sensing is to address the spatial and temporal resolution of atmospheric measurements. Improved temporal resolution observations of the atmosphere – and importantly a reduced latency between observation and delivery to the user – can directly improve weather forecasting services.

In this SysNova call, the target is to achieve a revisit at 40° latitude of once every hour with a resolution of better than 20 km. No single LEO remote sensing spacecraft could come close to this target – it has to be tackled by a constellation of satellites, and for this approach to be cost effective, the satellites should be low cost and small to minimise launch costs. Nanosatellites designed to suitable quality levels fit the bill very effectively.

To that end, SSTL and its partners the Met Office, NEXT Ingegnerio and the Surrey Space Centre have developed and studied a mission concept for ESA for providing tropospheric measurements cost effectively and with a low latency to the user segment. This solution, named ORORO (Orbital Radio Occultation and Reflectometry Observers), not only achieves the operational requirements within the €60M budgetary requirement, but also provides an additional payload data stream on sea surface state, with global coverage and exceeds the design lifetime by up to 100%.

In this study we highlight the benefits of using GNSS-RO (Radio Occultation) observations for Numerical Weather Prediction (NWP), climate monitoring, atmospheric phenomena observations and space weather. GNSS-R (Reflectometry) is also investigated, and although the data exploitation routes are less established compared to GNSS-RO, shows promise for complementary measurements of surface winds and various other parameters.

The advantage of GNSS Remote Sensing is that it can achieve many of the features of mono and multi-static radar remote sensing without need for any transmitters, as they are carried by the GNSS satellites themselves. All that is required is an adaptation of a GNSS receiver based on COTS software-definable technology. Technological advances have enabled GNSS SDR hardware to become small enough to fit nanosatellite platforms, and so enable a constellation of satellites sufficiently small for a multiple launch together.

Missions such as COSMIC have demonstrated benefits of GNSS-RO for atmospheric sounding, while the new NASA CYGNSS mission pioneers the use of GNSS-R on a constellation for surface wind measurements. The next major step is to combine these two complementary and technologically similar observations – using all three major GNSS Constellations – into one instrument, and this is what the ORORO concept has at its core.

Some of the key findings of this study are:

- A 30 nanosatellite constellation can be developed, built, launched and operated for under €60M.
- In less than one year of operation, this constellation can provide more data than COSMIC-1 provided in its whole mission lifetime.
- Using the expertise of the consortium, the data output of the mission concept has been compared to what is actually needed by the meteorological community and is found to be of value and useful.
- After launch integration and separation systems are considered, the mass and cost savings of using a 12U spacecraft over a 27U spacecraft are negligible.
- The power generation capabilities of a 27U spacecraft are such that the platform can sustain 100% duty cycle for forward-looking and aft-looking Radio Occultation observations, and also maintain 100% duty cycle on GNSS Reflectometry observations.
- The mission can be built today, using existing technologies with minimal spacecraft-level and payload-level NRE, and would provide useful data to meteorologists worldwide before the end of the decade.

This study has demonstrated real viability for the ORORO mission concept. It is strongly recommended that the study is taken to second phase, where further work analysis can take place, particularly on payload antenna design and novel funding concepts.

1 MISSION DESIGN

The mission objective, as stated in the SysNova Weather Challenge statement of work, is "to perform measurements of tropospheric properties (e.g. temperature, pressure, humidity and winds on rapidly evolving timescales in support to weather forecasting of severe weather events such as convective thunderstorms, cyclone(s), hurricanes etc."

The MET office – as users of data from space-based assets, can derive many of these parameters from GNSS RO observations. In this respect, it is not only the quality of the observations that is important, but also the number of observations per day that is important for meteorologists implementing global numerical weather models. Additionally, the Met Office could also use GNSS reflectometry to derive other data sets such as surface wind speed.

Combining these two objectives, we can generate a more specific mission objective, which is to measure GNSS signals, both transformed by the Earth's atmosphere and through specular reflection off the Earth's surface, to determine tropospheric properties, globally, with a data volume sufficient enough to be at least adequate for meteorological use ("threshold" values"), or approaching data volumes high enough to provide "breakthrough" data sources.

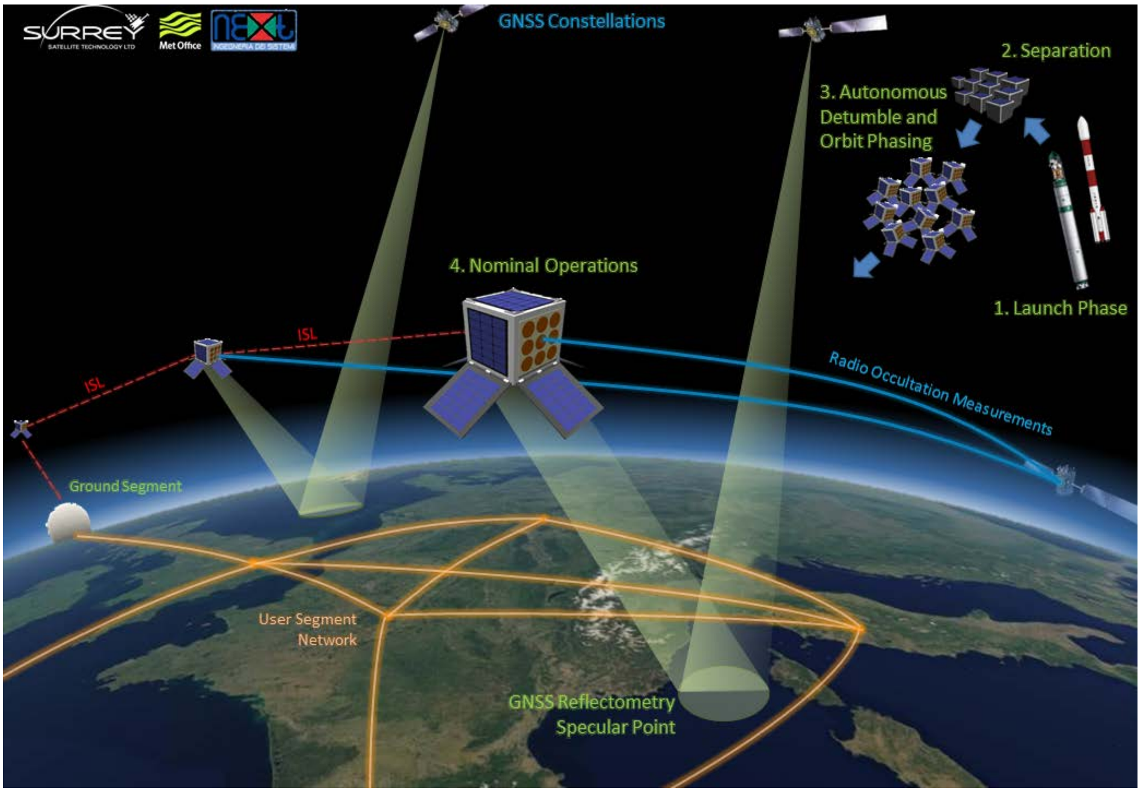


Figure 1-1: SysNova Weather Nanosatellite Challenge Mission Concept

The constellation design has been greatly constrained due to the relatively low budget and high launch costs. For this reason, the only orbits which have been considered are orbits with reliable low cost launch opportunities whilst still providing the desired coverage.

Sun Synchronous orbits (SSO) provide the desired coverage over all latitudes and provides regular lighting and thermal conditions. Due to this there are numerous launches to SSO each year. EO satellites tend to use SSOs with LTANs at 06:00, 09:30 to 10:30 and 13:30, so launches to these orbits will be more available.

The altitude of the orbits has been limited to 550 km to comply with the debris mitigation guidelines. This has the added bonus of providing approximately 1.2 dB reduction in the free space path loss for reflectometry measurements when compared with TechDemoSat-1 which is in a 635 km SSO.

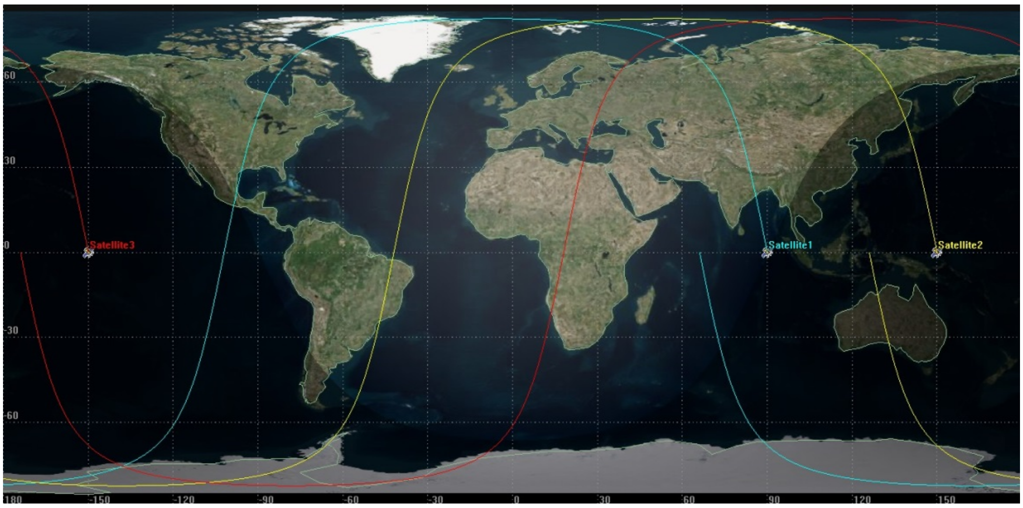


Figure 1-2: SSO constellation ground tracks

The space segment will comprise of a launch segment which has been shortlisted to PSLV or Dnepr, and a constellation of 30 spacecraft that are all of the same nanosatellite design for the purpose of fore and aft GNSS RO observations, and nadir-pointing reflectometry observations, distributed equally over three planes (10 spacecraft in each plane). A containerised solution is preferred due to the innate benefits to the main launch payload, and the simplified interfacing to the launch vehicle that containerised deployment abstraction provides.

1.1 CONCEPT OF OPERATIONS

1.1.1 LEOP

In order to simplify the safety analysis for launch, a standard policy of launching the spacecraft in an unpowered, passive state will be adopted. It is assumed that all the weather monitoring nanosatellites will be released simultaneously, or within quick succession, and so a period of inactivity will need to be observed before the solar panels can be deployed autonomously. This must relatively quickly however, as until that point the spacecraft will be active but running on battery power only.

After the mandatory period of inactive drift and autonomous solar panel deployment, all the spacecraft will need to be commissioned. Given the number of spacecraft, a manual process for each spacecraft from a single ground segment and MOC would be laborious and costly, and so it would be more prudent to include software resident on the spacecraft at launch capable of autonomous check out of all platform subsystems and detumble the spacecraft (first to Y-Thomson then to nadir-pointing), ready for payload check-out by human operators on the ground, and constellation phasing (which are expected to occur somewhat simultaneously).

1.1.2 Constellation Phasing

In-plane phasing of the satellites will be performed using the AOCS to hold the satellites in a high drag orientation or “shuttlecock” mode. The increased drag will cause the altitude of the satellite to reduce due to it the loss of energy. The relative velocity between the satellite and the other satellites in nominal flight mode will therefore increase. The satellite is then allowed to drift relative to the other satellites until it reaches desired angular separation. This process is repeated, staggered in time, with each satellite to achieve the full phasing. The angular separation required for a 10 satellite per plane system is 36°. As can be seen in Figure 1-3, it takes 30 days for a satellite to reach this state.

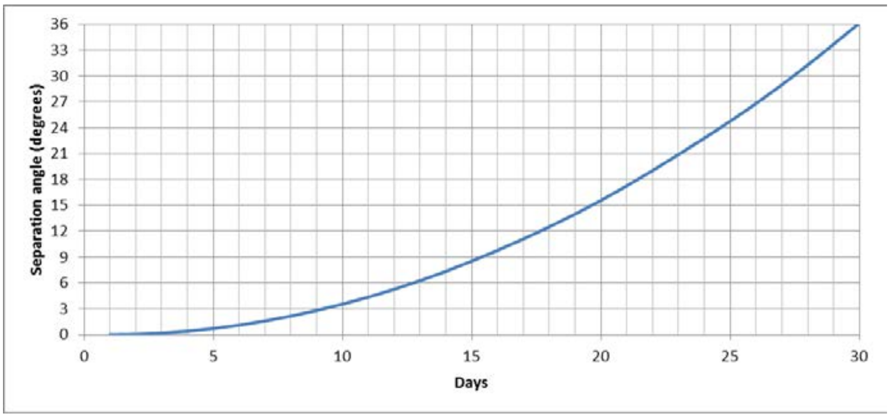


Figure 1-3: Required drag manoeuvre time frame for ORORO

After the drag manoeuvre is complete for a satellite, it has a higher orbital velocity than the pre-manoeuvre satellites. This means that the time it takes to reach the a further 36° separation from the position in the original orbit is less than during drag mode in which the orbital velocity was increasing. This is the crucial parameter which dictates time step between satellites entering drag mode to achieve phasing. For the 0600 LTAN orbit this time step was 19.4 days which results in a time of 204.6 days to achieve full phasing. A diagram explaining this procedure can be seen in Figure 1-4.

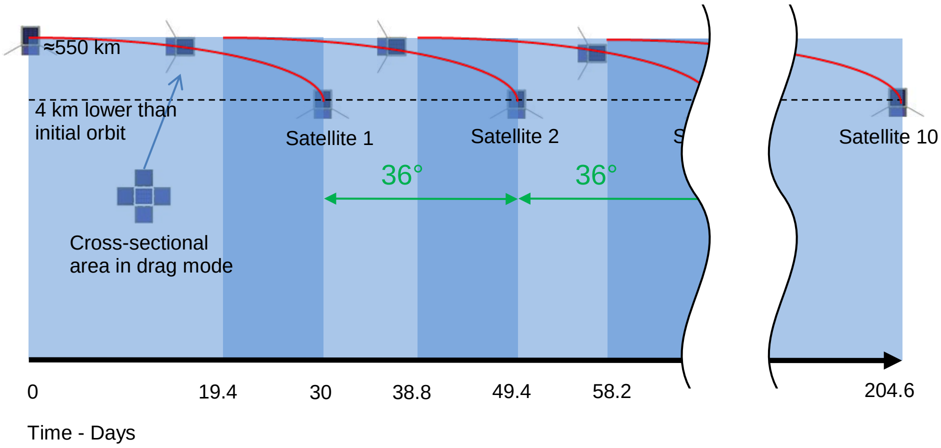


Figure 1-4: In-plane spacecraft phasing procedure

1.1.3 Payload Commissioning

Payload commissioning is expected to take approximately 2 days per spacecraft. Using a conditional “sked”, the spacecraft OBC will autonomously go through each test, stopping only if a non-nominal result is encountered. The spacecraft will report back the results of the test regardless of if the commissioning programme passed or failed.

The GPS dual frequency mode (GPS L1, L5) will then be tested, initially for 1 orbit, then 24 hours.

Multi-constellation PNT mode will then be evaluated over a whole orbit, at which point the payload transitions in to the more scientific modes for commissioning:

1. Radio Occultation – GPS L1 / L5 only mode – 1 orbit
2. Test full GNSS Nav/RO/R mode – 1 orbit, then in 2 hour slots, then 24 hours operation.
3. Raw GPS (/ Galileo) reflection collection – 1 orbit
4. GPS / Gal / Glonass DDM collection – 1 orbit

1.1.4 Nominal Operations

The satellites are flying in three orbital planes with a constellation control centre devoted to their M&C and to the management of the TT&C stations. Mission operations are based on managing the Satellite to Ground visibility at a pace of two contacts/orbit/satellite so requiring a specific planning on ground for the use of the stations and, consequently, for the data transmission and reception from satellite.

1.1.5 Safe mode and FDIR

By using the standard X-series suite of avionics, the spacecraft will make use of the standard X-series FDIR strategy. In this strategy, the TM/TC module acts as a watchdog for platform operations. This is robust because the TM/TC unit is

a) The only unit where both the primary and redundant units are permanently powered

b) The unit with direct control over the power state of all other units via the power control bus

c) The unit with direct link to the ground, and with capability to inject low level commands directly from operators on the ground on to the telecommand bus (CAN)

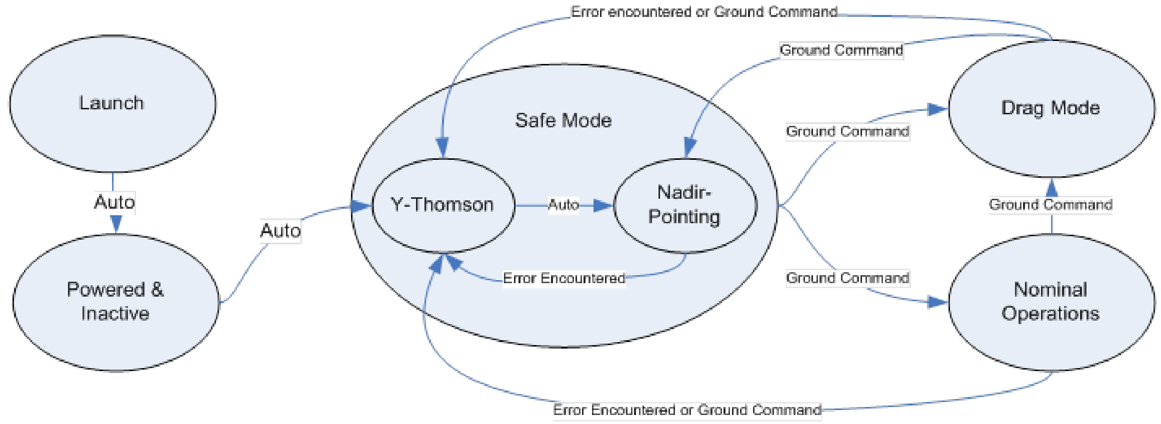


Figure 1-5: State transition diagram

The modes show in Figure 1-5 are described further in Table 1-1.

Table 1-1: AOCS modes

State	Description
Launch	S/C completely unpowered, battery bus disconnected (bus switch physically closed on separation), Solar Panels Stowed
Powered & Inactive	S/C Powered, all equipment OFF except Transceiver 0 and Transceiver 1, Panels stowed for fixed amount of time then deploy signal given and panel deploy mechanism fired
Safe Mode Y Thomson	Transceivers on, primary OR secondary OBC on, AOCS task in Y Thomson mode
Safe Mode Nadir Pointing	Transceivers on, primary OR secondary OBC on, AOCS task in Nadir pointing mode. All payloads OFF
Drag Mode	Transceivers on, primary OR secondary OBC on, AOCS task in drag mode. All payloads OFF
Nominal Operations	Transceivers on, primary OR secondary OBC on, AOCS task in Nadir pointing mode. Payload 0 OR 1 ON and active

1.1.6 Deorbit

The limitations on the mass of the spacecraft mean that actively deorbiting the satellites will be unrealistic if the primary mission is to be achieved. For this reason the altitude of the orbit that the satellites will be inserted into will be limited to ensure re-entry within 25 years. Altitudes above 560 km have lifetimes of longer than 25 years so an altitude of 550 has been selected as this will allow for launch insertion error and remain compliant to the debris mitigation guidelines.

Deorbit analysis shows that for the worst case orbit, with the 10:00 LTAN, the satellite deorbits naturally in less than 18 years. The first 5 years of the mission the satellites will only drop 10 km which, if they remain operational, should allow them to provide consistent data.

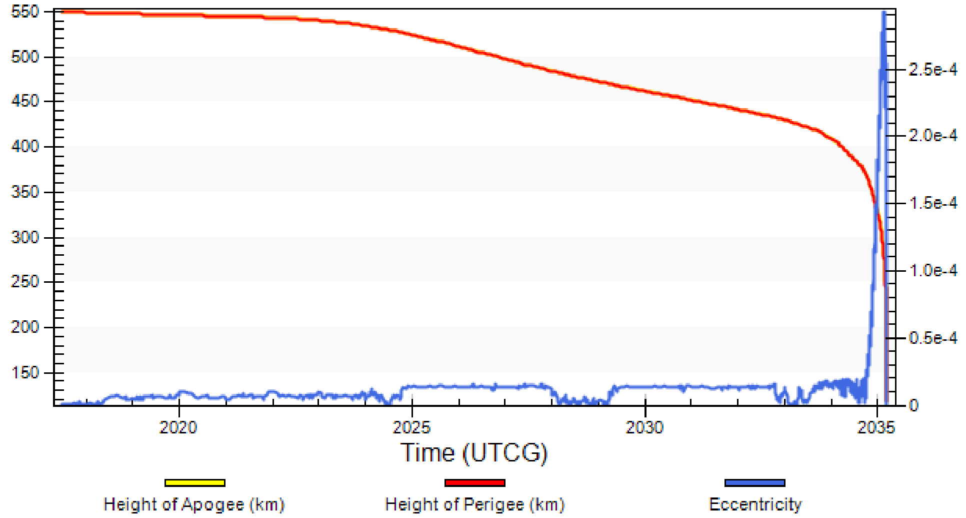


Figure 1-6: Deorbit analysis for satellites in the 1000 plane

2 PAYLOAD DESIGN

The aim of the payload design is to achieve the state of the art in both GNSS-Radio Occultation and GNSS Reflectometry measurements, but maintain the small size and power that is an enabler for the constellation.

The SGR-ReSI used on TDS-1 is designed with additional flexibility to demonstrate radio-occultation and multi-constellation operation – and has sufficiently low power to be considered for the ORORO. A platform version of the SGR-ReSI is now being produced called the **SGR-Axio** that has been modified for a smaller footprint, lower power operation – the only capability lost compared to the SGR-ReSI is on-board raw data storage, though that can be achieved by way of connection to an external data recorder.

The full requirement for achieving radio-occultation and reflectometry simultaneously from multiple constellations places an excessive burden on the SGR-Axio processor. Therefore a further upgrade to the two SGR-Axio processors is anticipated to fulfil the mission, but the architecture remains essentially unchanged, and the instrument upgrades are described below.

The architecture of the SGR-Axio is shown in Figure 2-1.

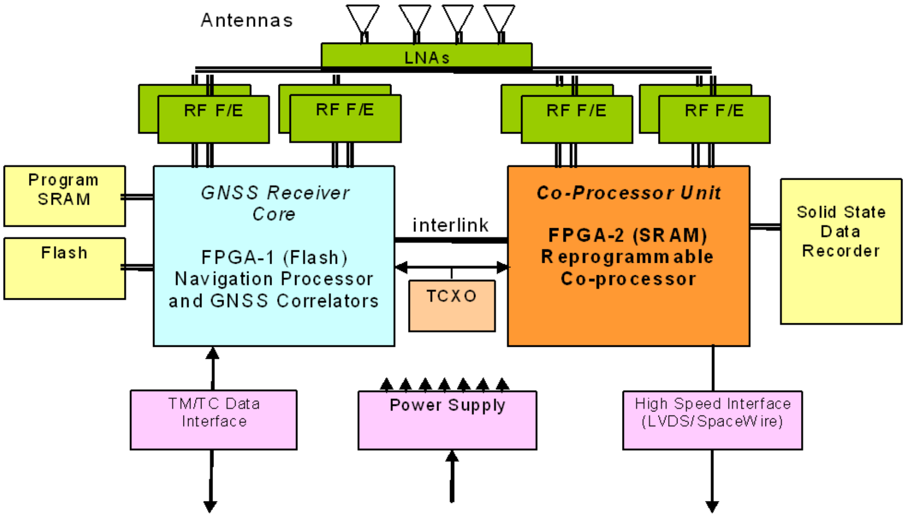


Figure 2-1: SGR-Axio Generic Architecture

The SGR-Axio carries 8 separate RF front-ends, enabling up to 4 dual frequency antennas to be supported. Two varieties of COTS-based RF front-ends have been incorporated, one of which is L1 optimised (MAX2769) while the other is re-configurable to any of the GNSS bands (MAX2112).

The SGR-Axio uses FPGA (Field Programmable Gate Architecture) technology for processing and flexibility that allows for both positioning and remote sensing. The Pro-ASIC 3E is a non-volatile Flash-based FPGA that consumes little power. It contains the processor and up to 24 channels of SSTL-developed correlators, plus other peripherals, such as UART, CAN-bus, and SPI. The LEON3 SPARC processor is implemented as a soft core, with the selection of RTEMS to allow control over multitasking application software, portability between different processors, and compatibility with other developments at SSTL.

While the first FPGA contains the core functions of a GNSS receiver, a second FPGA is available as a co-processor. This is a Xilinx Virtex 4 FPGA that is SRAM based, allowing the upload of new co-processing algorithms even while in orbit. It enables special processing algorithms for reflected or occulted signals, allowing the equivalent of hundreds of correlators to map the distorted signals.

The receiver supports multiple interfaces (CAN, RS422, SpaceWire, and USB), is around 1 kg in mass, consumes less than 10 watts, and fits within a box of approximately 150 x 160 x 50 mm.

2.1 CONFIGURATION OF INSTRUMENT

The availability of 4 dual frequency front-ends allows the SGR-Axio to support the antennas required for the ORORO mission. Figure 2-2 shows how the four RF inputs would be connected.

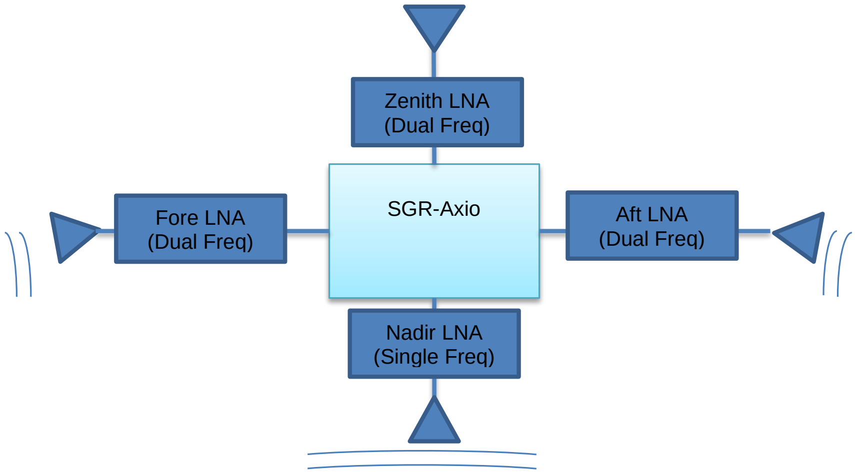


Figure 2-2: ORORO Payload Configuration based upon SGR-Axio

1) **Zenith antenna** to pick up dual frequency signals from GPS. These signals would be used for on-board position, and taking pseudorange and phase measurements for precise orbit determination, and thirdly taking reference measurements from all constellations for the reflectometry.
2) **Fore and Aft antennas** would pick up dual frequency signals from GPS, Glonass and Galileo after refraction through the atmosphere.
    - 3×2 element phased array antennas
    - 30° horizontal, < 30° vertical boresight gain pattern
    - >10 dBiC gain
3) **Nadir antenna** – for scatterometry there is only need for a single frequency antenna, though altimetry applications may look for dual frequency reflections.
    - The only single frequency antenna
    - 3×2 element phased array antenna
    - 30° boresight gain pattern
    - 13 dBiC gain

The low noise amplifiers are required to support a switched load and temperature sensor for calibration purposes, while still maintaining a low loss.

2.2 INSTRUMENT PROCESSING

GNSS-RO relies on tracking GNSS signals as the satellites set behind (aft of) the satellite. The measured phase and amplitude of these signals are captured to recover the bending angle of the atmosphere. As the satellites set, the rate of measurement is increased from 10 Hz to 50 Hz to achieve the required vertical resolution. When the signals become too weak or begin to break up, the receiver must switch to open loop mode, where the delay and Doppler of the tracking channel are placed by prediction and not by tracking loop error signals. This approach can also be used in reverse to acquire signals from the front-pointing, or fore, antenna as the GNSS satellites rise.

GNSS-R As reflected signals are weak and unpredictable; all tracking is done open loop. For the co-processor to generate Delay Doppler Maps of the sampled reflected data, it needs to be primed with the PRN, the estimated delay and the estimated Doppler of the reflection as seen from the satellite. These are calculated by the processor in conjunction with the main navigation solution - the data flow for this is shown in Figure 4. Direct signals (from the zenith antenna) are used to acquire, track GNSS signals. From the broadcast Ephemerides, the GNSS satellite positions are known. Then from the geometry of the position of the user and the satellites, the reflectometry geometry can be calculated, and hence an estimate of the delay and Doppler of the reflection.

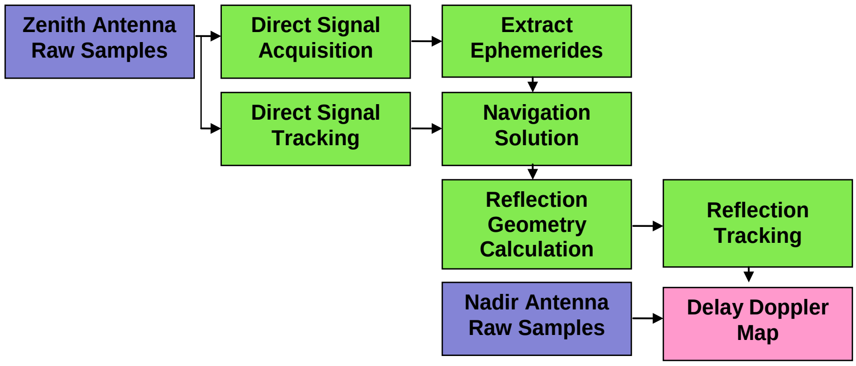


Figure 2-3: Reflectometry Processing

The processing of the Delay Doppler Map is performed on the coprocessor using data directly sampled from the nadir antenna (Figure 2-4). In common with a standard GNSS receiver, the local PRN is generated on board the co-processor. As an alternative to synchronising and decoding the reflected signal in a standalone manner, the direct signals can be used to feed the navigation data sense, and assist the synchronisation. The sampled data is multiplied by a replica carrier and fed into a matrix that performs an FFT on a row by row basis of the Delay Doppler Map, to achieve in effect a 7000 channel correlator, integrating over 1 millisecond. Each point is then accumulated incoherently over hundreds of milliseconds to bring the weak signals out of the noise.

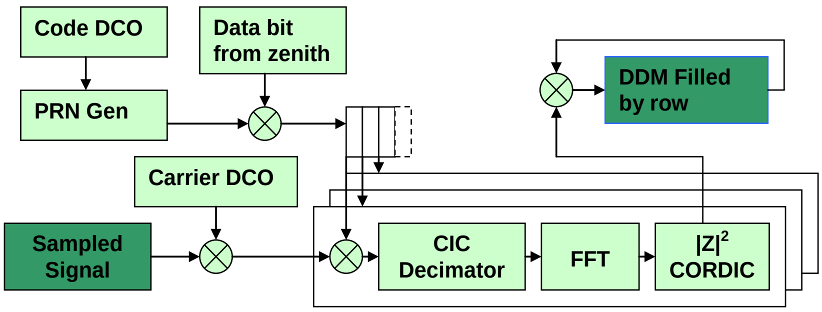


Figure 2-4: Delay Doppler Map Processing

This processing is performed in real-time on board the satellite and greatly reduces the quantity of data required to be stored and downlinked, enabling a larger number of reflections to be captured.

2.3 FREQUENCY & SIGNAL SELECTION

Dual frequency signal reception is required to compensate for the atmosphere both in precise orbit determination and in taking refracted radio-occultation measurements through the ionosphere. The initial choice has been GPS L1 (1574 MHz) and L2 (1227 MHz). The L1 signals are narrow band, but the L2 signals have been wideband and encrypted, requiring codeless tracking through signal squaring or cross-correlation. A new civil signal, L2C has emerged on the same frequency that is narrow band and unencrypted, so can be tracked more simply, giving a stronger signal. If only GPS were being used, then the choice for dual frequency would be L1 and L2C – these are the signals supported by TDS-1 GNSS-R experiment.

Modernised GPS, however, has commenced transmitting a civil broadband at L5 (1176). This may be a better choice for the second frequency, as it doubles up with Galileo E5a (1176) and is close to Glonass G3 (1202). The choice of frequencies is complex, and there are several options available, such as choosing a wide enough band that covers L2 and L5.

For the moment it is assumed that L1 and L5 will be selected as the dual frequency bands, with a bandwidth enlarged to allow both Glonass G1 (1600) and G3 (1202).

3 MISSION PERFORMANCE ANALYSIS

3.1 RADIO OCCULTATION

To study the potential performance of RO measurements of the constellation a simulator was developed in Matlab to assess the:

- Total number of occultations over the course of 24 hours
- Spatial distribution of the occultations
- Occultation profiles for individual ORORO satellites to determine duty cycles

The total number of occultation and the spatial distribution of the measurements provide a measure of the performance of the system to allow it to be compared to other systems. This is dependent on the measurement ceiling, that is to say, the highest altitude tangent point which is measured during an occultation profile.

The scenario was designed to contain a constellation of 12 ORORO satellites with 3 planes each containing 4 satellites. The simulation was initially run with only the GPS constellation, consisting of 30 satellites, which produced 4169 occultations per day. Later the GLONASS constellation, consisting of 22 satellites, was added into the scenario. The number of occultations per day increased to 6005. This showed an approximately linear relationship between the number of occultations and the number of satellites which allowed for the calculation of the number of occultations that each ORORO satellite will see for each GNSS satellite per day. This allowed the number of radio occultations including the currently unfinished Galileo constellation to be included (see Table 3-1 and Table 3-2)

Table 3-1: Breakdown of predicted occultation measurements per day performance with a measurement ceiling of 120 km

Occultations/day (total)	6005
Occultations/day/ORORO	500.4
Occultations/day/ORORO/GNSS	9.6
Occultations per day: 30 ORORO satellites 76 GNSS (30 GPS + 24 Galileo + 22 GLONASS	**≈22,000**

Table 3-2: Breakdown of predicted occultation measurements per day performance with a measurement ceiling of 450 km to include the ionosphere

Occultations/day (total)	28455
Occultations/day/ORORO	2371.25
Occultations/day/ORORO/GNSS	45.6
Occultations per day: 30 ORORO satellites 76 GNSS (30 GPS + 24 Galileo + 22 GLONASS	**≈100,000**

Figure 3-1 shows the occultation distributions produced by the simulation and increasing altitudes ceilings. The distribution of these occultation measurements is reasonably uniform. This allows a means horizontal spatial separation to be determined. By the dividing the surface areas of the Earth by the number of occultations per day and taking the square root gives a separation of 154 km for a measurement ceiling of 120 km. This falls to 70 km with a measurement ceiling of 450 km. If the same calculation is made for COSMIC-1 data the mean separation is 292 km.

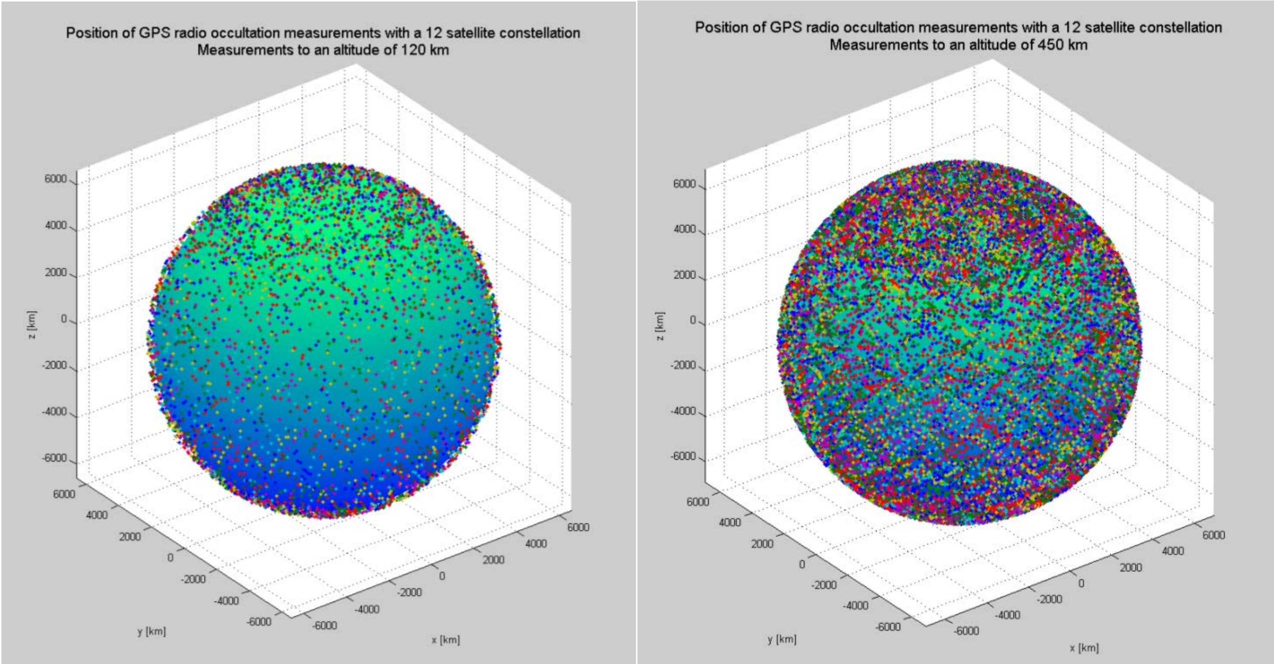


Figure 3-1: Occultation up to 120 km and up to 450 km

A 30 satellite constellation with measurements at least up to 120km would meet the basic requirement for NWP. For climate and space weather applications the measurements to higher levels (i.e. 450km) are required and even for NWP there may be some benefit as the ionospheric correction could be improved but this is rather speculative. The analysis undertaken by Harnisch et. al. (2013) suggests the benefit to NWP increases even up to 120,000 occultations per day. However it should be borne in mind that there will be several other satellites with the capability of making RO measurements (e.g. EPS, Chinese FY-3, GRACE, various research satellites) to enhance the coverage and so a 30 satellite constellation would go a long way to increasing the current capability. It is important to emphasise that global coverage is required for all applications. Also it should be noted that two RO observations with identical tangent points, measured at the same time, will not be completely redundant if the azimuths are different. The use of other navigation systems such as GLONASS, Galileo, and Beidou should also be seriously considered to increase the coverage over the standard GPS system. Experiments underway at the Met Office with the receivers on the FY-3C satellite are already demonstrating the improved coverage when the Beidou system is used in addition to GPS.

3.2 REFLECTOMETRY

To analyse the reflectometry another Matlab simulation was used to provide coverage maps. This process is not as simple as standard imaging coverage maps as the coverage is dependent on the position of the specular point within the bore sight of the nadir antenna. The position of the specular point is dependent on the positions of the ORORO satellite and the GNSS satellite. The size of the specular point will also vary as it is dependent on the surface roughness of the ocean. For the purposes of this simulation the size of the specular point was set to 50 km diameter.

This tool was used to investigate the coverage produced by different constellation designs. The constellation designs where limited to those with popular orbits. SSO provides coverage across all but a small area at the poles which will be covered in ice. A drawback of SSOs is that the coverage is at its greatest at the poles and reduces towards the equator. With 10 satellites per plane, between the tropics the percentage of the ocean surface per latitude not covered does not exceed 1% over 24 hours.

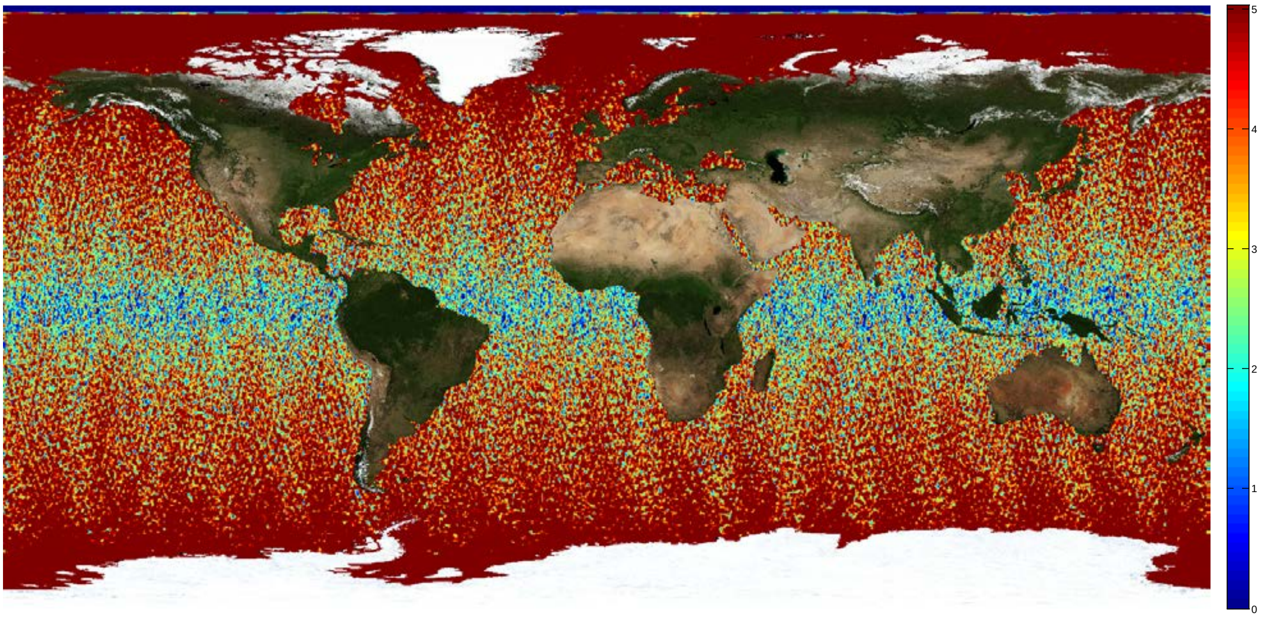


Figure 3-2: Coverage over one day with 3 SSO planes with 10 satellites per plane

GNSS reflectometry data has not been assimilated in operational NWP systems to date but the hope is it will improve the poor coverage currently available from the scatterometers in the METOP orbital plane. Operating in the L-band it also has a greater 'all weather' capability than scatterometers. However the capabilities of this new technique still need to be proven. Preliminary indications are suggesting an accuracy of 1.65 m/s in surface wind speeds (Clarizia et. al. 2014) for these measurements. However it is not clear over what area these measurements are averaged over. This accuracy is potentially useful for higher wind speed regimes (normally in the extra-tropics) but not for low wind speeds. The orbital configurations shown here suggest two SSO planes and one i=51° plane give the best coverage for GNSS-R applications. Given there will always be an EPS satellite with a scatterometer on board in a morning/evening orbit (LT ascending node 21:30) there could be some merit to prioritise the SSO planes to be complementary to this. SMOS, another satellite potentially measuring surface winds using L-band, is in a 35 day repeat orbit however it has no continuity so shouldn't influence future coverage analyses.

4 PLATFORM DESIGN

The baseline design is the X-Nano 27U platform. The subsystems are a mixture of new developments, heritage SSTL systems, CubeSat components and systems developed as part of the SSTL X50 platform development.

COTS separation systems do exist, the mass, power and volume available to the payload is greater, and the spacecraft is still small enough that launch costs per spacecraft are comparatively low. Additionally, the 27U form factor approaches the ideal Spacecraft Utility value (ScU), as defined in SSC14-V-4, and so in terms of utility “sweet spot” for spacecraft sizing, the 27U option is selected as the baseline concept for this study.

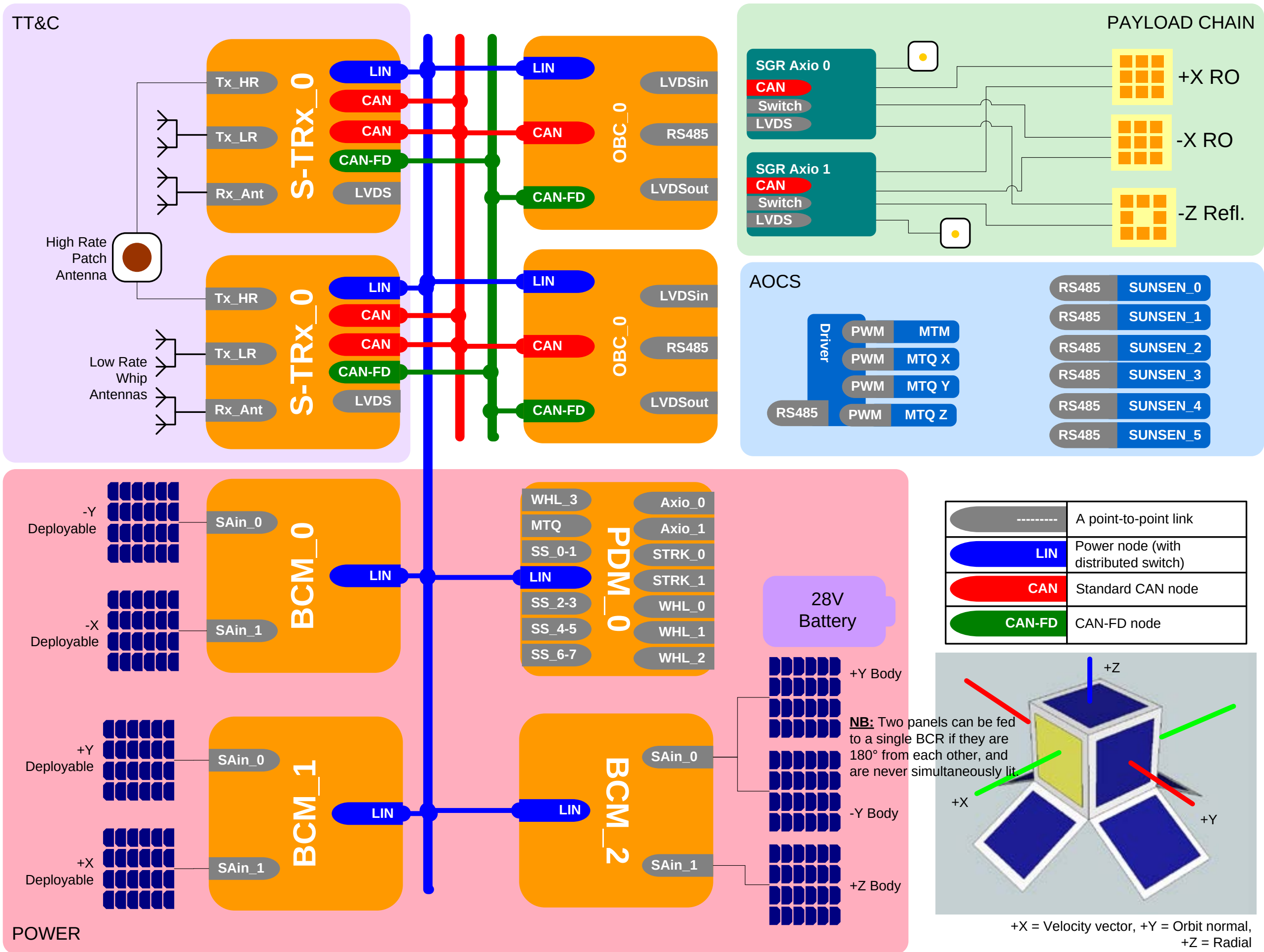


Figure 4-1: System block diagram

Adhering to the CubeSat standard simplifies the structural design process. Smaller CubeSat structures tend to be single-component frames, either with solid walls or skeletonised walls for accessibility during AIT. At the scale of 27U CubeSats however, other assembly philosophies can be considered. The approach selected for this mission is load bearing panels, made out of solid walled material (Aluminium or Carbon Fibre, to be traded at a later date based on mass budget considerations), avoiding the complexity of corner fixings through honeycomb structured panels.

The side panels mount via rugged hinges to the base plate, allowing the structure to be “unfolded” for access to the inside of the structure for AIT. This approach is the same the high level approach taken for the assembly of the Myriade platform, and more recently, the SSTL X-50.

Avionics modules are mounted on to the inside face of each side panel, with two modules mounted per side. The battery module is mounted to the baseplate (the Earth-facing panel), and the payload electronics are mounted above the battery.

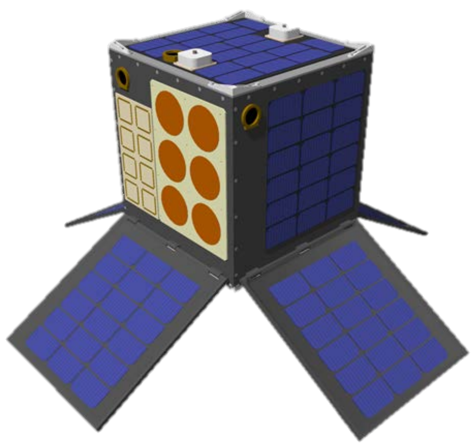
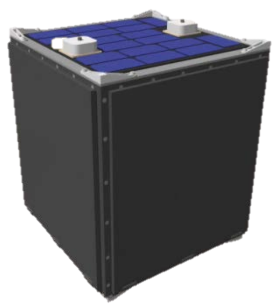
Peripheral equipment is mounted either on the remaining space available on the side panels, or on the inside face of the top panel.

Once three of the side panels are closed up, the top panel (Zenith-pointing) is attached, and any equipment mounted to the top panel is harnessed up. The final panel is closed and the solar panels and payload antennas are fitted.

In a similar vein to its smaller brethren, the structure is fitted with “feet”, allowing the spacecraft to be stacked within a containerised deployer, similar to the P-POD concept.

The 27U structure has overall dimensions of 30 × 30 × 30 cm whilst in stowed configuration with the deployable panels marginally smaller than the body panels.

Table 4-1: Baseline design

Platform Characteristics			
Constellation	30 satellites		 
	3 x SSO w. LTAN: 06:00, 10:00 &14:00		
	Altitude: 550 km		
Mass	19.9 kg		
AOCS	3-axis stabilised		
	Sensors	2 x Magnetometers	
		6 x Sun Sensors	
		2 x GPS receiver	
		3 x Magnetorquers	
Power	Solar Arrays	Solar Cells: 28.5% efficient 3J GaAs	
		3 x Body mounted Panel	
		4 x Deployable panel	
		4 x Hinge	
		4 x HDRM	
		OAP 30-40 W	
	Battery	1 x 120 Wh Lithium Ion	
	Conditioning	3 x BCM	
		1 x PDM	
		28V unregulated bus	
OBDH	OBC	2 x OBC	
Comms.	S-Band	2 x Transceivers	
		1 x Patch antenna	
		4 x Monopole antenna	
Thermal	MLI, Thermometers		
Structure	Aluminium frame structure		
	6 x Carbon fibre panel		
Payload	Antenna	Reflectometry - Nadir	
		Radio Occultation - Fore	
		Radio Occultation - Aft	
		2 x GPS reference patch	
	Instrument	2 x SGR-Axio	
Performance	Reflectometry	Duty cycle: 100%	
	Radio Occultation	20000 - 100000 per day	

5 GROUND SEGMENT DESIGN

The key drivers for the ground segment design are the global coverage requirement [ESAR003] and the less than 60 minute data latency requirement [ESAR006]. The Ground Segment can be assumed as composed of two main blocks as sketched in the following figure.

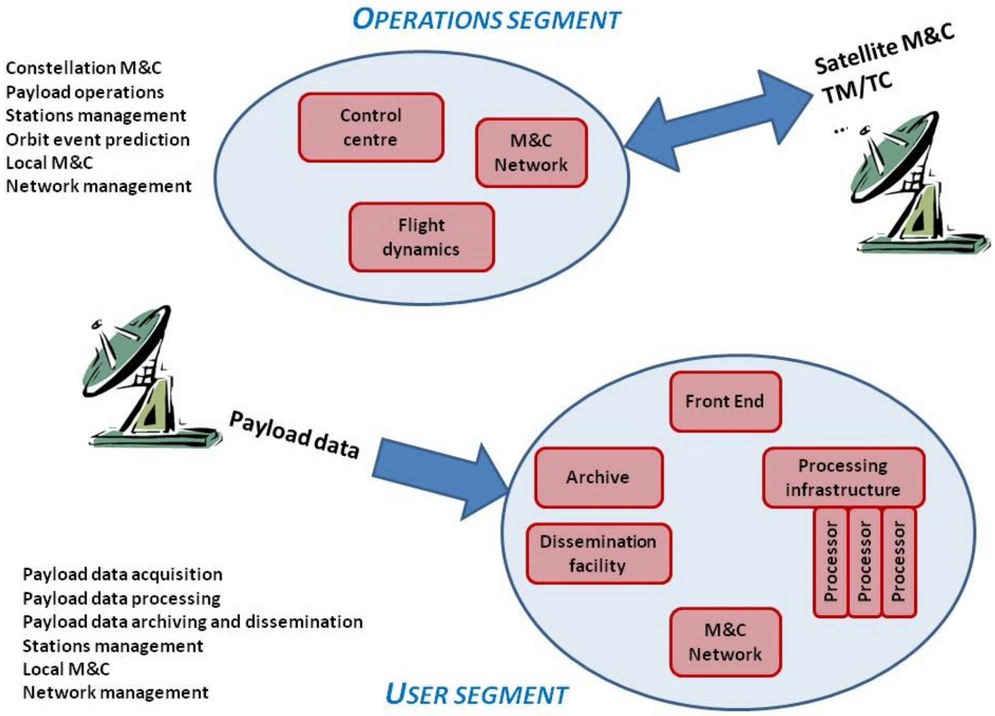


Figure 5-1: Ground segment

The ground segment components and their top-level functionality are listed below.

1) Operations Segment (OS) implementing:
    a) constellation M&C functions (TM, TC, OBSM)
    b) constellation flight dynamics functions (AOCS, Attitude, ...)
    c) payload acquisition planning functions
    d) TT&C functions
    e) local M&C functions
2) User Segment (US) implementing:
    a) data acquisition and repatriation functions
    b) processing functions
    c) archiving functions
    d) dissemination functions
    e) local M&C functions

For the purpose of matching the latency requirement, two acquisition stations must be foreseen for data acquisition on ground, a north-polar (Svalbard) and a south-polar one (Troll). This is to allow having two downlink opportunities per orbit so that the downlinked data are acquired on ground with a maximum latency as long as half orbit – i.e. around 48 minutes – so still allowing some 12 minutes for repatriation, processing and dissemination. In case the ISL is used on-board, this could result in avoiding the use of a southern station whose operations are typically more expensive because of the higher data communication costs.