Alphasat

Alphasat I / Inmarsat-XL (Inmarsat-Extended L-band Payload) / InmarSat-4A F4

Overview Spacecraft Launch Mission Status Payloads Ground Segment References

Alphasat is a mobile communications service spacecraft in GEO of Inmarsat Plc. of London, UK, referred to as Inmarsat 1-XL. It uses the first next-generation European **Alphabus** platform and carries in addition to the commercial Inmarsat payloads four hosted **TDPs** (Technology Demonstration Payloads) of ESA (European Space Agency). The Alphabus/Alphasat project is covered by the ARTES-8 (Advanced Research in Telecommunications Systems) European program. The four hosted payloads on Alphasat I are: [1)]

• TDP1: An advanced LCT (Laser Communication Terminal) representing a further development of already existing flight hardware on TerraSAR-X, NFIRE and TanDEM-X. The objective is to demonstrate GEO-LEO ISLs (Intersatellite Links) of high data rate transmissions (optical link at 1064 nm, 1.8 Gbit/s user data rate), complemented with a Ka-band payload developed by Tesat Spacecom (Germany). The payload is funded by DLR.

• TDP5: Two experimental Q/V-band communications transponders to assess the feasibility of these bands for future commercial applications - developed by TAS-I and Space Engineering, Italy.

• TDP6: Demonstration of an advanced Star Tracker with active pixel detector - developed by Jenoptik of Germany.

• TDP8: Demonstration of an environment effects facility to monitor the GEO radiation environment and its effects on electronic components and sensors - developed by Effacec (Portugal).

In November 2007, ESA, Inmarsat Global Ltd. and their prime industry partner (EADS Astrium) signed a contract for the development of the Alphasat spacecraft to augment Inmarsat's BGAN (Broadband Global Area Network) service. The contract inaugurated the first major European **PPP** (Public-Private-Partnership) program initiative. An important goal of this contract with the commercial communications operator is to allow an early flight demonstration and in-orbit validation of the Alphabus, the new European high-power telecommunications platform. [2)]

Already in March 2006, ESA and CNES (Space Agency of France) signed a cooperation agreement for the development of Alphabus, Europe's next generation platform for telecommunication satellites. The agreement followed the signing of a contract in June 2005 between ESA, CNES, EADS Astrium and TAS (Thales Alenia Space), former Alcatel Alenia Space, who jointly committed to the Alphabus development program. [3)]

The original ESA/CNES preparatory program for the Alphabus was approved by the ESA Member States at the Ministerial Council meeting in Edinburgh in November 2001. Subsequently, in 2003 an industrial and commercial agreement was signed between EADS Astrium and Alcatel Space (now Thales Alenia Space) for a joint Alphabus product line covering 12-18 KW payload power. The current contract, for the design of the product line and production of a first Proto Flight Alphabus, was signed as a four party undertaking in June 2005 with a joint ESA and CNES customer team and the co-prime contractors EADS Astrium and Thales Alenia Space (Ref. 6).

The ARTES-8 Alphabus/Alphasat program has the following objectives: [4)] [5)]

• Develop and qualify, together with CNES (Centre National d'Etudes Spatiales) and industry, a generic product line for Alphabus based on ground qualification of development and engineering models.

• Procure a flight-standard platform (protoflight model) to facilitate early first flight opportunity (in the frame of Alphasat).

• Consolidate a Large Platform Mission combining ESA-funded payloads with institutional and/or commercial payloads, allowing the in-orbit demonstration of a protoflight large platform.

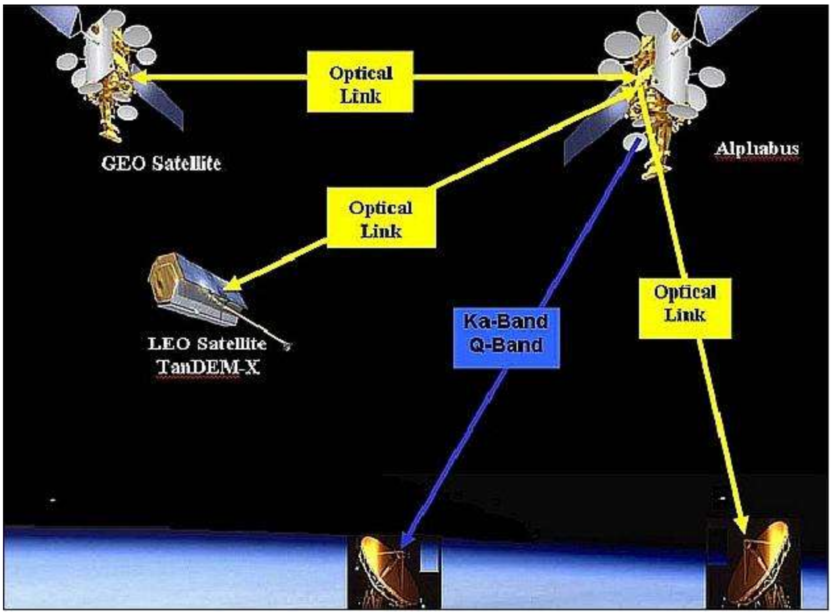

Figure 1: Illustration of communications links with Alphasat I-XL (image credit: ESA, TAS)

Spacecraft:

The Alphasat satellite utilizes the protoflight model of the **Alphabus** platform, developed by the co-prime contractors Airbus Defence and Space (formerly EADS Astrium) and TAS (Thales Alenia Space). The Alphabus extends the European Industry potential of its telecommunication satellite range significantly, beyond the capabilities of the existing platforms, such as Eurostar 3000 and Spacebus 4000, both with respect to maximum payload power and mass. The Alphabus contract covers the development, and qualification of a complete product line, with the following nominal capability requirements: [6) 7) 8) 9) 10) 11)]

- Spacecraft design life: 15 years

- Payload power: 12-18 kW (conditioned power)

- Spacecraft mass: Up to 8100 kg at launch (Alphasat-I has a launch mass of 6650 kg)

- Payload mass: Up to 1200 kg

Typical communication payload capacity: up to 200 transponders, equivalent to more than 1000 TV channels, SDTV (Standard Definition Television) and more than 200,000 audio channels.

The Alphabus product line is designed for future growth and will be compatible in its extended version with higher payload power (up to 22 kW), higher payload dissipation and a higher payload mass (up to 1400 kg).

The basic design features of the Alphabus are:

• Structure: Central tube and additional carbon and aluminum panels:

- Section 2800 mm x 2490 mm

- Launcher Interface: 1666 mm

• Chemical propulsion:

- 500 N apogee engine and 16 10 N RCTs (Reaction Control Thrusters)

- 2 propellant tanks (max 4200 kg of bi-propellant)

- Helium tanks (2 x 150 liter)

• Electrical propulsion:

- Xenon tanks (max 350 kg)

- PPS 1350 thrusters on TOM (Thruster Orientation Mechanisms)

• Power generation and distribution:

- 2 GaAs solar array wings with 4 to 6 panels

- Power supply and power distribution offering both 100 V and 50 V regulated buses

- Modular Li-ion battery

• Modular concept based comprising an Antenna Module for easier antenna accommodation and efficient assembly and test

• ADCS (Attitude Determination and and Orbit Control Subsystem)

- Gyros

- Star and Sun Sensors

- Reaction Wheels

• Data handling through a 1553 bus for payload.

On June 16, 2011, the Alphabus platform was formally accepted for its first satellite, Alphasat I-XL. The platform

Airborne Sensors
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Related Links

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provides unrivalled payload capacity to operators for commercial satcom missions and services such as fast Internet to remote locations, high-definition and 3D digital TV broadcast, and communication to mobiles. In addition, the high-power platform offers opportunities for Europe's satcom industry and ESA to work together to develop cutting-edge technologies for new services such as air traffic management or security communications. [12)]

The first Alphabus satellite, Alphasat I-XL, developed in partnership with European operator Inmarsat, uses the platform's full potential.

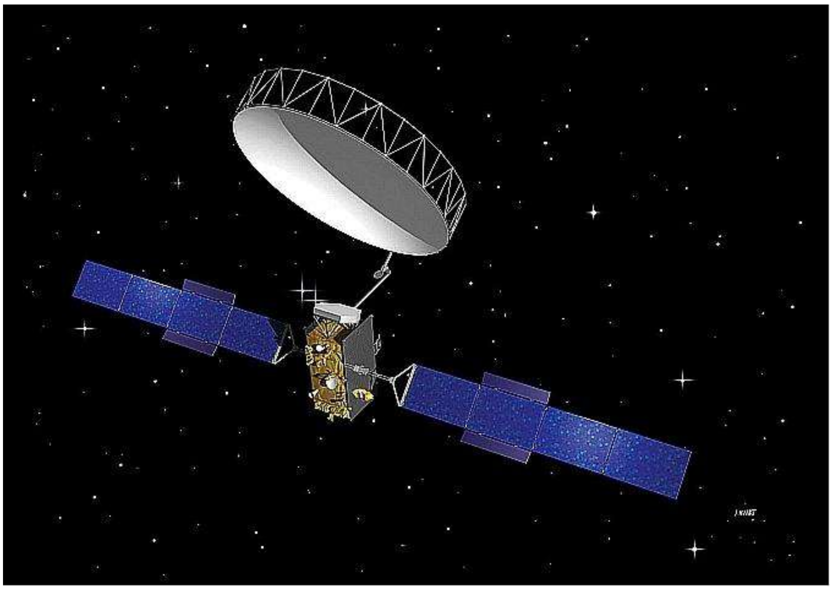

Figure 2: Artist's rendition of the deployed Alphasat I spacecraft (image credit: ESA, Ref. 6)

Spacecraft architecture:

The Alphabus platform is based on a scalable modular architecture consisting of three modules: SM (Service Module), RM (Repeater Module), and AM (Antenna Module). The design permits parallel integration and tests of the standardized SM, as well as the mission-specific three-floor RM. [13) 14)]

The SM is built around a large central tube (1.6 m) embedding two large propellant tanks with a maximum capacity of 4200 kg, and provides the mechanical interface with the launch vehicle for a launch mass of up to 8,800 kg.

The RM itself is split in two halves, allowing parallel integration of the repeater units with an accommodation capacity doubled compared to what is available today. It is mounted on top of the SM.

The use of an ‘ultrastable' antenna module structure for the Earth-facing side allows the efficient mechanical alignment of the antennas and their accurate pointing towards Earth. It can also include lateral arms to hold large antenna reflectors on the lateral sides of the satellite, if required by the mission. The antenna module structure is under development by RUAG Space (Switzerland).

The overall structure has been developed by Thales Alenia Space Cannes (France). The central tube was developed by EADS Casa (Spain) and is based on state-of-the-art carbon fiber placement technology offering high strength and low mass.

Figure 3: Photo of the Alphabus service module (right) and Alphasat repeater module stand side by side before the mating procedure at Astrium SAS (image credit: Astrium)

SM (Service Module): The SM is the core unit of the Alphabus development, subject to the common ESA-CNES phase C/D contract. Its development followed a classical approach with a design and validation phase, concluded by a qualification at units, functional chains, then at system levels. It took into account the specificities of a product line with the need to cover a large performances domain. Furthermore, some provisions for future extension capabilities were introduced since the beginning (e.g. the option of including several deployable radiators).

The Alphabus Service Module consists of the main structure, the central tube, internal deck and several other structural elements equipped with thermal hardware, the chemical propulsion system with the main apogee boost motor, the pressure control assembly with three Helium tanks and the two large propellant tanks inside the central tube, as well as part of the plasma propulsion system with, in particular, the Xenon tanks. [15)] [16)]

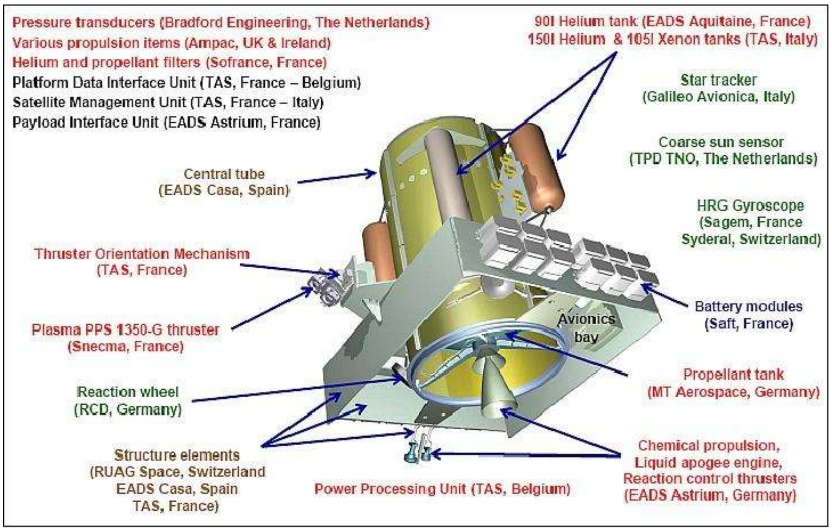

Figure 4: Allocation of Service Module element manufacturing to European companies (image credit: CNES)

Figure 5: Photo of the Alphabus Service Module (image credit: TAS, ESA)

Electrical propulsion: The electrical propulsion subsystem is based on four plasma thrusters used for north/south on-orbit stationkeeping of the satellite. The system is an evolution of an existing design (heritage of SMART-1 mission of ESA, launch Sept. 27 2003) and consists of proven hardware with flight heritage. The plasma thruster, PPS 1350-G, was developed by Snecma (France), and its control electronics PPU (Power Processing Unit), come from Thales Alenia Space ETCA (Belgium).
Two thruster orientation mechanisms, developed by TAS in Cannes, hold two thrusters each and allow orientation in two perpendicular directions. The system includes two off-the-shelf xenon fuel tanks of 68 liter each; however, larger xenon tanks each of 105 liter are being developed at Thales Alenia Space in Italy.

Figure 6: Illustration of the PPS 1350-G thruster (image credit: Snecma)

Chemical propulsion: The Alphabus CPS (Chemical Propulsion System) is a helium-pressurized bipropellant system

using monomethylhydrazine (MMH) as the fuel and mixed oxides of nitrogen (MON-3) as the oxidizer. It has a 4200 kg total propellant mass capacity scalable down to 3500 kg, with 16 reaction control thrusters and a 400 N apogee engine. EADS Astrium Lampoldshausen (Germany) is responsible for the CPS subsystem and provides the reaction control thrusters and apogee engine along with most CPS components. A new high-efficiency 500 N apogee engine is being developed at EADS Astrium Lampoldshausen.
The titanium carbon-fiber over-wrapped propellant tanks were developed by MT Aerospace. With a volume of up to 1925 liter and a dry mass of < 85 kg, they are among the world's largest yet lightest satellite tanks ever built.

ADCS (Attitude Determination and Control Subsystem): The very accurate and flexible ADCS of Alphabus is inherited from the zero-momentum, four-reaction-wheel control concept of the Spacebus® 4000, with three-axis determination using a star tracker and an accurate on-board orbit propagator and precise on-board time. It also includes a gyroscope and a coarse sun sensor. The reaction wheel has been developed by RCD (Rockwell Collins Deutschland GmbH of Heidelberg, formerly known as TELDIX GmbH) in different versions (angular momenta of 18, 25 and 50 Nms); a new active pixel sensor-based star sensor was developed by Galileo Avionica (Italy); a new Hemispherical Resonator Gyroscope was developed by Sagem (France) with Syderal (Switzerland) and a new coarse sun sensor was developed by TNO TPD (Netherlands Organization for Applied Scientific Research, Delft, The Netherlands).

ATS (Antenna Tracking System): ATS is being used for high-accuracy antenna pointing. ATS is based on radio-frequency sensing in order to reach 0.05º half-cone target performance. Up to eight antennas can be controlled by the ATS. This system allows for individual pointing control of each antenna, compared to the standard ADCS body control, hence compensating for each beam-specific error with a higher control bandwidth. An onboard closed loop is implemented in the onboard software.

Solar panels: The solar generator, inherited from Eurostar E3000, is scalable from four to six panels per wing. The 10 m^2 panels are fitted with triple junction solar cells from Azur Space (Germany) and will benefit from the continuous efficiency improvements of gallium arsenide (GaAs) cell technology. When needed, the fifth and sixth panels are deployed laterally from the third in-line panel.
During launch and early orbit operation, one panel per wing is deployed and provides sufficient power for the satellite electrical power balance. The solar array was developed by EADS Astrium in Ottobrunn (Germany). The low-shock release mechanism was designed also by EADS Astrium Ottobrunn and manufactured by RUAG Space. The high-power solar array drive mechanism was developed by EADS Astrium, Stevenage (UK).

EPS (Electrical Power Subsystem): The overall electrical configuration has been designed to allow efficient powering of payload units. A primary 100 V regulated power bus with structure return is distributed to payload units with aluminum bus bars protected through decentralized fuse boxes. The 100 V PSR (Power Supply Regulator) and the lithium-ion modular battery configuration allows for efficient power regulation. The PSR was developed by EADS Astrium SAS (France). The battery modules and their latest generation 'G5' lithium-ion battery cells were developed by Saft (France) for Alphabus. The fuse box was developed by EADS Astrium Crisa (Spain). [17) 18)]

The core element of EPS is based on a high Power Supply Regulator named PSR100V, designed by Astrium. A 100V regulated bus has been selected for Alphabus as the more suitable at system level for very high-power satellites for telecom missions. The PSR100V is in charge of powering the spacecraft from solar array panels in sunlight mode and from 1 or 2 batteries during eclipses.

The PSR100V, or PCU (Power Conditioning Unit), is based on a modular approach and of Astrium's Eurostar heritage. Its internal architecture is designed to comply with the reliability target with a single unit per spacecraft. A set of PMs (Power Modules) connected in parallel allows the PSR to convert the onboard available energy into a 100 V regulated power bus. To fulfil this mission, two functions are implemented in a power module:

• The ASR (Array Switch Regulator) that converts the energy of the solar arrays in sunlight mode.

• The BDR (Battery Discharge Regulator) that converts the energy of the battery in eclipse mode.

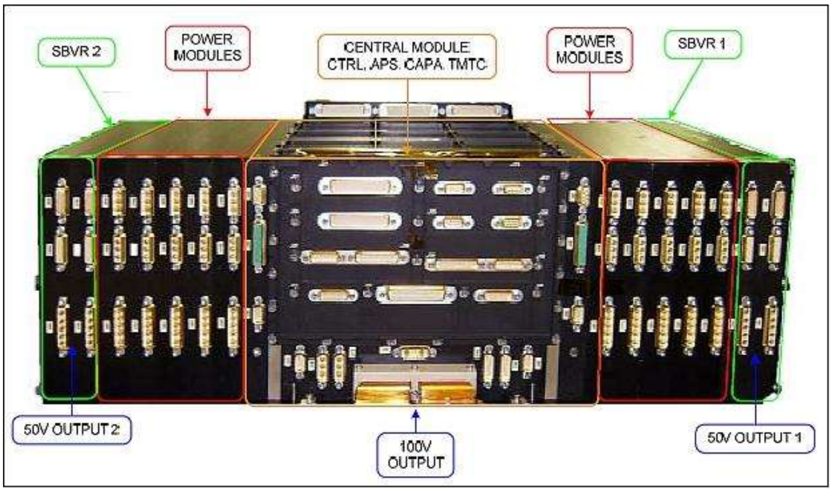

Figure 7: The PSR100V unit with 10 PMs and 2 SBVRs (image credit: Astrium SAS)

The CM (Central Module) that embeds:

• The TM/TC (Telemetry and Telecommand) interfaces and communication link with spacecraft computer through 1553B protocol

• The control functions for start up, bus voltage regulation and battery charge management

• The centralized 100 V bus capacitor tank.

The PSR100V can embed as an option one or two SBVR (Second Bus Voltage Regulator), each delivering an autonomous and reliable 50 V @ 700 W power bus. This option allows the user to preserve compatibility with existing platform units.

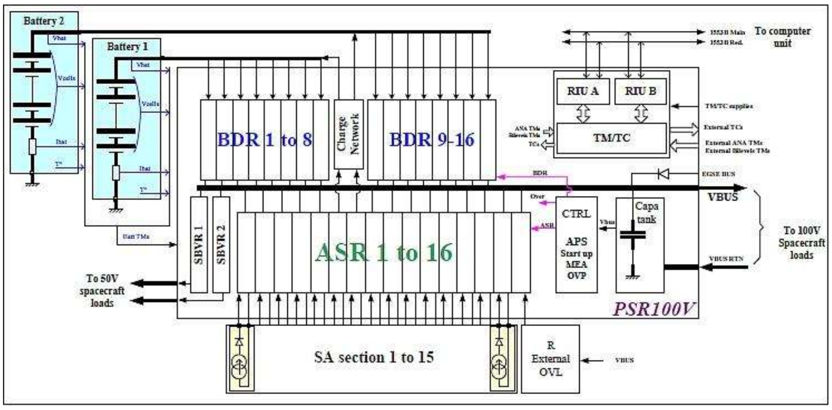

Figure 8: Functional block diagram of PSR100V (image credit: Astrium SAS)

The SBVR (Second Bus Voltage Regulator) has been developed and qualified on ESA's Alphabus program in order to supply existing 50 V platform units. So it has been designed with the same reliability and FMECA (Failure Mode and Effects Analysis) constraints as the one applied to the 100 V bus generation.

The SBVR is an autonomous function connected internally to the 100 V bus with the same mechanical modularity concept as PM. One or two SBVR modules can be added, limiting the NR (Non-recurring) cost effort to internal power bus bar adaption. The topology choice makes it possible to regulate down to 28V with minor adaptation.

The SBVR is a fault tolerant power supply based on two step-down DC/DC converters operated in hot redundancy. Each DC/DC converter is implemented on a different module, in order to prevent any failure propagation from one channel to the other. A reliable output capacitor bank based on self healing capacitors provides a very low output noise and impedance.

Instrument size	750 mm x 247 mm x 348 mm
Instrument mass (specific power)	54.5 kg (373 W/kg)
Power generation capability	20.3 kW max (using 16 PMs, each PM delivers 1.35 kW)
Bus voltage regulation	100 V ± 1 V
Sunlight power conversion efficiency	98%
Eclipse power conversion efficiency	97%
Bus impedance (<100 kHz)	50 mΩ
Voltage ripple	< 600 mVpp
Battery voltage	55 to 96 V
Battery charge current	up to 40 A

Table 1: Performance characteristics of the PSR100V (or PCU)

The design of the EPS is capable of providing a large power range to match foreseeable future payloads. It provides as an option one or two reliable 50 V secondary buses to keep compatibility with existing platform units.

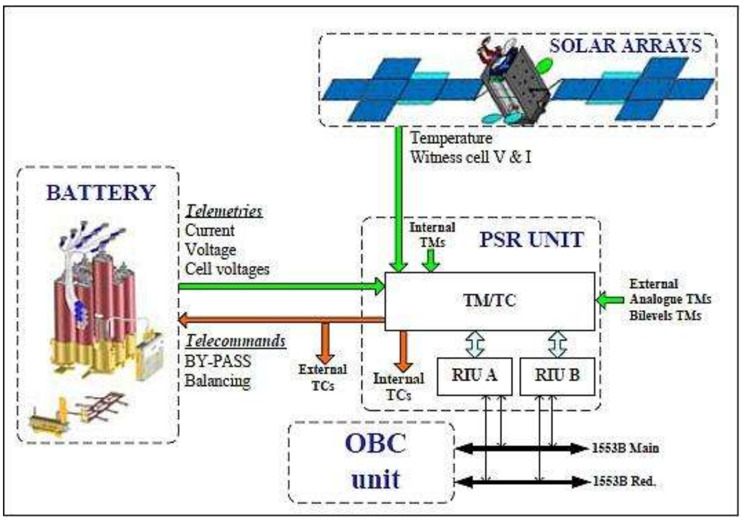

Figure 9: EPS TM/TC block diagram (image credit: Astrium SAS)

Figure 10: Photo of Alphasat after the mechanical test campaign in August 2011 (image credit: ESA)

The satellite mechanical test campaign has qualified the Alphabus platform for an Ariane 5 launch. The test campaign was completed in August 2011.

Spacecraft life time	15 years
Spacecraft mass, power	6650 kg (launch mass), 12 kW (conditioned power)
Payload mass	Up to 1200 kg
Bus structure	Central tube and additional carbon and aluminum panels - Section 2800 mm x 2490 mm - Launcher Interface: 1666 mm
Chemical propulsion	- 500 N apogee engine and 16 10 N RCT thrusters - 2 propellant tanks (max 4200 kg of bi-propellant) - Helium tanks (2 x 150 liter)
Electrical propulsion	- Xenon tanks (max 350 kg) - PPS 1350-G thrusters on thruster orientation mechanisms
Power generation and distribution	- 2 GaAs solar array wings with 4 to 6 panels - Power supply and power distribution offering both 100 V and 50 V regulated buses - Modular Li-ion battery - Wingspan of deployed sloar arrays: 40 m
ADCS (Attitude Determination and Control Subsystem)	- Gyros - Star and sun sensors - Reaction wheels
Data handling	Use of a 1553 bus for payload data

Table 2: Alphasat I-XL key performance parameters

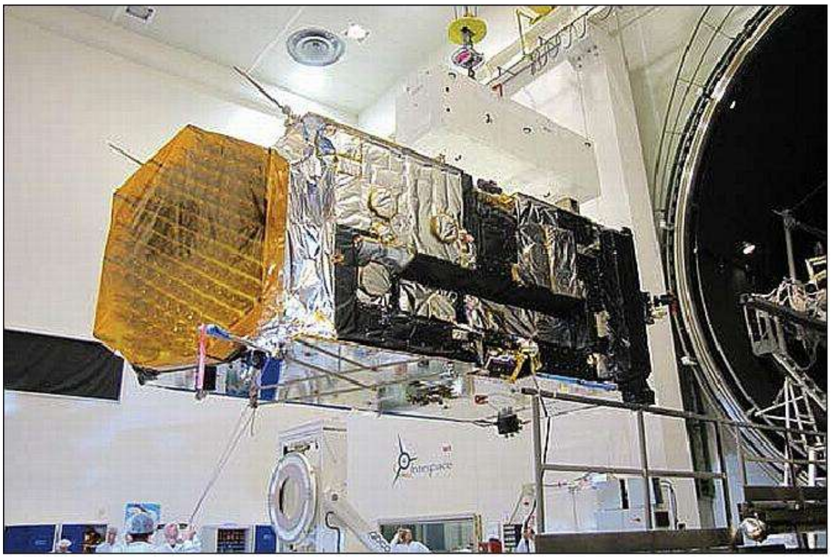

Figure 11: The Alphasat spacecraft entering the thermal vacuum chamber in Toulouse in late November 2012 (image credit: Intespace) [19] [20]

Figure 12: Photo of the Alphasat being lowered onto the Arianespace flight adapter in Kourou (image credit: ESA) [21]

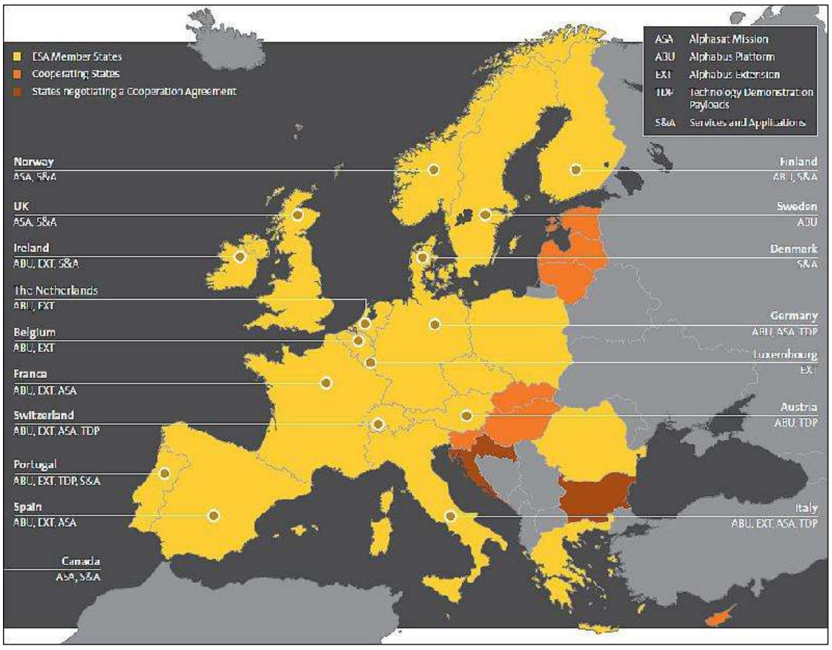

Figure 13: Participating States in Alphasat and Alphabus in the complex PPS (Public Private Partnership) program (image credit: ESA, Ref. 11))

Launch: The Alphasat I/Inmarsat 1-XL/Inmarsat-4A F4 spacecraft (6650 kg) was launched on July 25, 2013 on an Ariane-5 ECA vehicle from Kourou. The Ariane-5 ECA vehicle took off at 19:54 GMT and delivered Alphasat into the target GTO (Geostationary Transfer Orbit about 28 minutes later. - Alphasat's signal has been picked up by an Inmarsat ground station in Beijing as expected at 20:38 GMT, confirming that the satellite is at the predicted location, powered up and transmitting. 22) 23)

Passenger payload: **INSAT-3D**, a geostationary weather satellite of ISRO with a mass of ~ 2100 kg, was the passenger payload on this flight.

Orbit: GEO (Geostationary Orbit), altitude ~35,756 km, longitude = 25º E.

Mission status:

• March 25, 2015: Inmarsat has announced the successful transition of key L-band voice and data services from its I-4 F2 satellite to Alphasat, the telecommunications satellite developed by Inmarsat in partnership with ESA (European Space Agency). 24)

- According to Inmarsat, services including FleetBroadband were transferred overnight during a regular maintenance window. Both satellites will continue to jointly provide services over the EMEA (Europe, the Middle East and Africa) region until the remaining two services (L-TAC and IsatData Pro) still carried out by the I-4 F2 are also transferred to Alphasat. - This is scheduled to happen by the end of Q2 2015, whereupon the I-4 F2 will be flown to a new orbital position to create a fourth L-band region, serving the Middle East and Asia (MEAS). Commercial services, including FleetBroadband, are due to begin operation in this new region by the end of 2015.

• On February 3, 2015 the two ground stations in Tito and Spino d'Adda were connected through Alphasat — providing the first 40/50 GHz satellite video conference. 25)

- The weather conditions were not the optimal ones for satellite links at those frequency: snowing in Tito and raining in Spino d'Adda. The modems were connected to camera in the two stations premises and the video conference took place.

• Nov. 28, 2014: First laser link transmission experiments between Alphasat in GEO and Sentinel-1A of ESA in LEO were successfully conducted using the experimental LCT (Laser Communication Terminal -TDP1) of Tesat Spacecom. The demonstration involved the transmission of Sentinel-1A images in near- realtime via Alphasat to ESA/ESOC in Darmstadt, Germany at a link speed of 1.8 Gbit/s. This important step demonstrates the potential of Europe's new space data highway to relay large volumes of data very quickly so that information from Earth-observing missions can be even more readily available. 26)

• Nov. 18, 2014: Hawaiian Airlines (USA) has announced it will be the first commercial airline installing Inmarsat's (UK) SB (SwiftBroadband-Safety), a new air safety service for trans-oceanic flights that has been designed and developed through ARTES Alphasat, a Private Public Partnership between Inmarsat and ESA. SB-Safety builds on Inmarsat's SwiftBroadband, the company's L-band-based satellite communications system for the aviation industry. Developed for use in the flight deck, it provides airlines with cockpit communication, both for operations and air traffic control, everywhere in the world. 27)

• Oct. 2014: Figure 14 shows a typical movement of the in orbit LCTs 2-axis Coarse Pointing gimbal mechanism during an acquisition phase. Prior to start of the link, the 2-axis LCT Coarse Pointing gimbal mechanism was commanded to the initial link position. At the start of the link, Alphasat TDP1 LCT was set as master terminal and performing spiral scans with its laser beam fine pointing mirrors in the direction towards the OGS (Optical Ground Station). This first phase lasted 120 seconds, during which the OGS was manually aligned to the center of the flashing signal. After alignment, the 10 W ground laser was activated towards the TDP1 LCT as phase 2 acquisition started (Ref. 44).

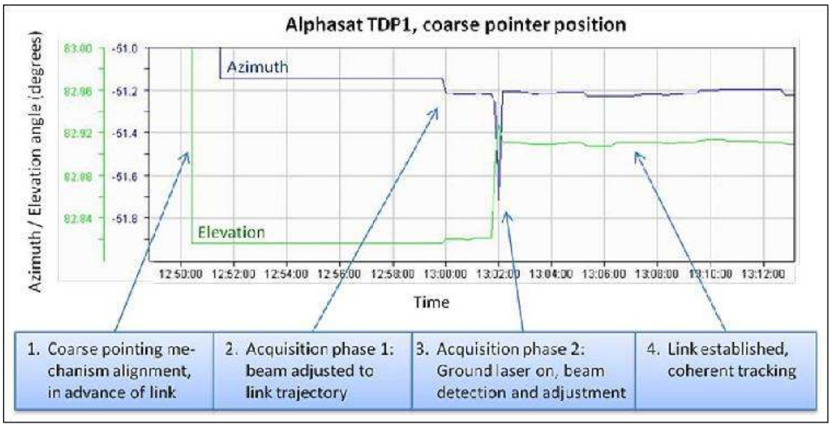

Figure 14: Beam steering mechanism position during link acquisition (image credit: Tesat)

- Now using its acquisition sensors and fine-steering mirrors, the Alphasat LCT aligned its optics to the OGS uplink beam and fulfilled the transition from coarse to fine acquisition. After both link partners were sufficiently aligned to each other, the signal was received by the LCT's four quadrant coherent detector and the LCT changed from acquisition phase to coherent tracking mode, keeping itself actively aligned onto the incoming laser beam from now on. During the described optical ground links, strong scintillation effects due to atmosphere and clouds were observed, causing deep signal fades. Yet, stable tracking was achieved even at RX intensities of less than 10% of the lowest specified RX intensity during a LEO-GEO link (Figure 15).

Only at much lower tracking sensor levels, when thick clouds interrupted the link, tracking was lost. In this case, the LCT automatically re-started the link acquisition by spiral scanning, resuming tracking as soon as clouds were passed. This was demonstrated for a high number of cycles. — In conclusion, the LCTs algorithms for spatial acquisition based on spiral scanning, the autonomous transition from spacial acquisition to tracking, and tracking under severe atmospheric conditions was demonstrated successfully between Alphasat as a GEO spacecraft and the ESA optical ground station located in Tenerife.

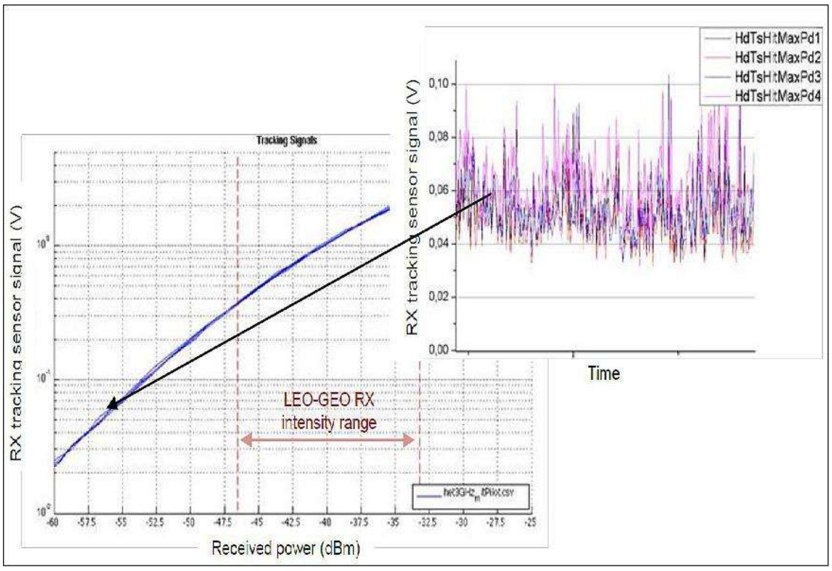

Figure 15: Coherent tracking at GEO-ground RX signal strength (inlay), much below LEO-GEO RX intensity (image credit: Tesat, Ref. 44)

• Competitiveness boost (Aug. 2014): The boost of competitiveness linked to the Alphabus and Alphasat programs can be clearly measured. Alphasat is now a key asset for Inmarsat, and the associated services developed under the ARTES program will benefit the maritime and aeronautical communities. For the satellite primes, some of the technologies developed and validated under Alphabus, such as power or plasmic propulsion, are now also largely incorporated into the subsystems of each of the primes main product lines. At unit level, the sensors, power supplies and digital processors developed under the Alphabus and Alphasat programs have all been actively marketed and sold on various other satellite program (Ref. 11).

- The TDP6 star tracker, for example, has been particularly successful on the commercial market, thanks in part to its qualification and in-orbit demonstration phase on Alphasat. TDP8 is expected to complement this success with its in situ measurement of the radiation environment in the most commercially relevant orbit (geostationary), while the Aldo Paraboni payload and the LCT (Laser Communications Terminal) will both be instrumental in demonstrating new telecommunications technologies in orbit and opening new commercial markets, as indicated by the interest they are triggering in an increasingly large international community.

- At system level, Alphabus is ready to address the upper range of the satellite telecommunications market and complement the existing European product offerings.

- Even though the current Alphabus platform has met its objectives on the ground and in orbit with the mission of Alphasat, an Alphabus Extension Program is running in parallel to further develop the capabilities of the product line. The main features being developed are, among others, additional spacecraft power for payloads up to 22 kW, increased heat rejection capabilities (up to 19 kW) including the addition of a Deployable Panel Radiator, and improved avionics.

• May 9, 2014: The ASTRO APS Star Tracker EQM successfully completed the qualification test campaign. The APS Star Tracker has shown excellent performance. It outreached the specified requirements especially in terms of accuracy and robustness to space environment (Moon, Radiation Robustness). The design expectations are very well met. [28)]

- The ASTRO-APS Star Tracker is well suited to fulfil the mission requirements of Alphasat, Small GEO, Sentinel-2 and EarthCARE, missions for which ASTRO-APS us currently contracted for.

• March 2014: Alphasat is in good health and is being routinely operated from Inmarsat's control center in London. The four Technology Demonstration Payloads were all tested by the end of 2013. [29)]

• January 21, 2014: European scientists can now begin probing unexplored frequencies, as mega telecom satellite Alphasat's 'Aldo Paraboni Q/V Band' hosted payload has been given the green light to begin experiments. [30)]

- Six months after launch, the payload has undergone many commissioning and in-orbit tests before receiving the go-ahead to start operations. The Q/V-band mission, named after the late Italian scientist Aldo Paraboni who inspired it, is one of four technology demonstration payloads carried by Alphasat. It is dedicated to exploring the higher-frequency Q- and V-bands at 38 and 48 GHz.

- With all tests now complete confirming the payload is healthy and performing well, the scientists can start conducting their experiments. They will be analysing the data from the two independent packages that make up the Aldo Paraboni payload.

• Nov. 20, 2013: Astrium, as prime contractor for Alphasat and responsible for LEOP (Launch and Early Orbit Phase) operations, confirms that **the first Alphabus platform is now fully operational**. [31)]

• Nov. 13, 2013: The LCT (Laser Communication Terminal) of Alphasat correctly identified its target at ESA's ground station on the island of Tenerife in the Canary Islands for the first time on Nov. 4, 2013, proving that it can be pointed precisely enough to hit a point more than 36 000 km away. [32)]

- The 'illumination test' involved the terminal beaming its laser from geostationary orbit to hit the ground sensors. It was the final stage of commissioning for this 'hosted' payload, and shows it is healthy and ready for the next set of tests: linking with the ground station and exchanging data.

- This technology demonstration payload, dubbed TDP1, is an optical communications and Ka-band downlink system built by German company Tesat Spacecom and furnished by the DLR (German Aerospace Center). It will demonstrate the use of laser technology for collecting information from the congested low orbits and then transmitting it to ground stations from its position high above in geostationary orbit.

• The LEOP (Launch and Early Orbit Phase) and part of the IOT (In-Orbit Test) activities were conducted from the Airbus Defense and Space facilities in Toulouse, with the hand-over to the Inmarsat SCC (Satellites Control Centre) in London on August 12, 2013.

• On August 3, 2013, Alphasat reached a temporary position (slot) in the geostationary orbit. It deployed its 11 m diameter main antenna over the course of a day – marking ten days in orbit and completing one of the final steps towards starting services. The spacecraft will stay in this slot for several weeks while Inmarsat together with ESA continue testing the telecom payload, the backup units on the Alphabus platform and ESA's four hosted payloads. [33)]

- Several major milestones have been met over the past few days, including rising to geostationary altitude after separation from its Ariane 5 launcher, and deploying its twin four-panel solar wings, spanning 40 m. The panels rotate automatically, following the Sun, while Alphasat's sophisticated attitude control system tracks its position above Earth.

- All of these milestones were assured by a team from Astrium, the Alphasat prime contractor, managed by Inmarsat. In a cooperative effort unprecedented in Europe, the team was supported by ESA and France's CNES space agency, as well as TAS (Thales Alenia Space) for Alphabus platform operations.

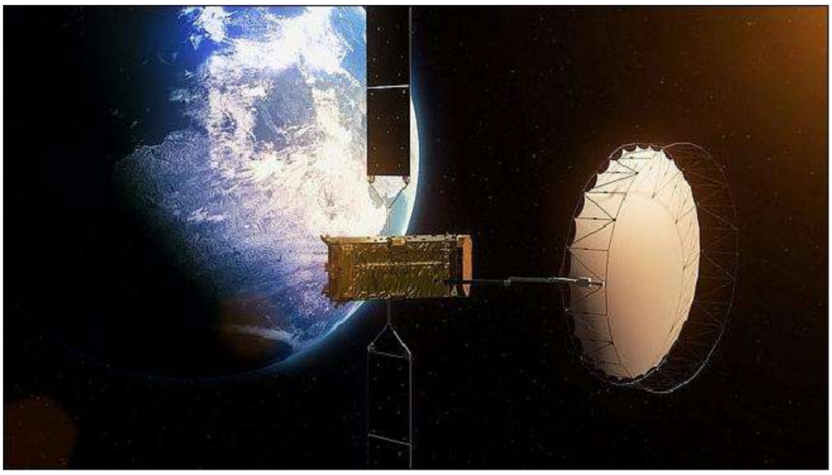

Figure 16: Artist's rendition of Alphasat (image credit: ESA)

Payloads of Alphasat I-XL:

Alphasat I-XL carries a commercial payload for Inmarsat - a new generation of advanced geomobile communications payload in L-band (1.6 GHz) that will augment Inmarsat's BGAN (Broadband Global Area Network) service, enabling communications across Europe, Asia, Africa and the Middle East with increased capacity. Alphasat I-XL features a new-generation digital signal processor for the payload, and a 12 m ∅ aperture antenna reflector. Alphasat I-XL is designed with increased capacity, 750 channels and 400-500 spot beams.

*Alphasat I-XL also carries the **hosted TDPs** (Technology Demonstration Payloads) for ESA (European Space Agency).* [34)]

Note: Only a few aspects of the commercial payload can be provided (due to a lack of information); the intent is to provide an overview of the hosted payloads of ESA.

Integrated Processor (IP): The IP, developed for the Alphasat mobile mission, is the latest evolution of Astrium's Digital Signal Processors product line – a technology that, for space applications. It is based on Astrium Next Generation Processor modular technology, which can be applied for other applications such as broadband and military missions (Ref. 10)).

Astrium's eight IPs are a core element of the leading-edge geomobile L-band communications payload, allowing allocation of capacity with an unprecedented flexibility through digital channelization and beamforming. It represents a major step forward in payload operational capability and commercial competitiveness.

The primary function of Alphasat's IPs is the routing and combining of channels to the desired beam. They are the key elements for the generation of spot beams and associated channel gain. This provides Alphasat with maximum flexibility in both frequency and power allocation to beams to meet traffic demands.

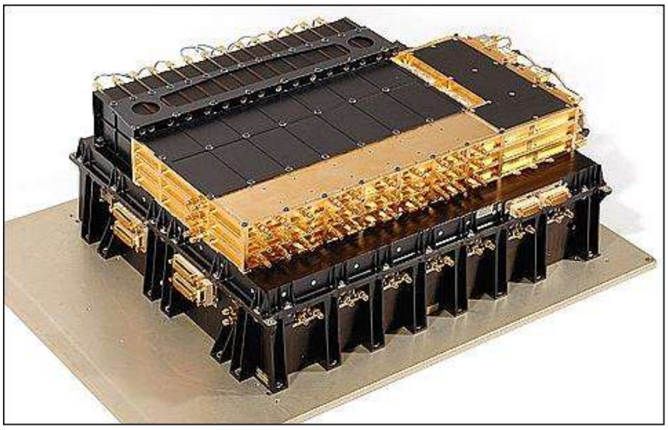

Figure 17: Photo of the IP assembly (image credit: Astrium)

The 8 IPs have a mass of ~ 250 kg and use the latest electronics technology to work in parallel on board Alphasat. The DPM (Digital Processing Module)in each IP includes 17 large ASICs (core computers) which contain all of the complex digital processing for routing and beam forming, providing Alphasat with a processing capacity which is unprecedented on board a commercial satellite: it can perform more than 10 trillion calculations per second!

Deployable AstroMesh Reflector of commercial payload:

Astro Aerospace of Carpentaria, CA (USA), a strategic business unit of Northrop Grumman Corporation, has delivered its fourth deployable AstroMesh reflector to Astrium in Toulouse, France, this one for the Alphasat I-XL spacecraft that will provide commercial, broadband telecommunications services (L-band) to Europe, the Middle East, Africa and parts of Asia. [35) 36)]

The reflector of 12 m aperture is the latest in a line of successful AstroMesh deployable, large aperture reflectors developed and built by Astro Aerospace. The reflector is a key part of the antenna system used by the spacecraft to provide broadband Internet communications. Enabled by the large reflector, the antenna system's sensitivity allows the use of mobile, laptop-size modems by users around the world.

Once the Alphasat satellite reaches orbit, ground controllers issue commands that control three hinge motors that unfold a 6 m boom supporting the reflector above the satellite. Additional ground commands are sent to two motors that unfurl the reflector to its fully deployed size.

• 112 kg subsystem mass (including boom & attachment hardware)

• 41 kg reflector only mass.

Alphasat I-XL features a new generation digital signal processor for the commercial payload.

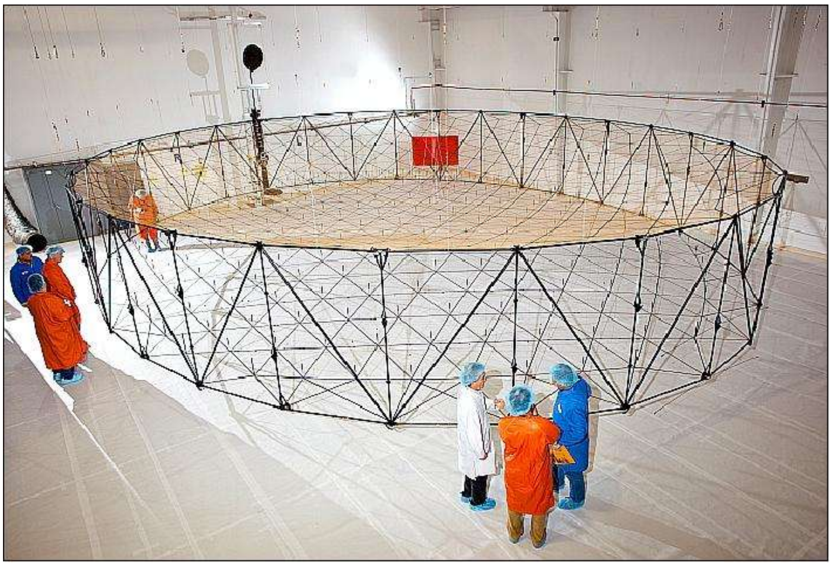

Figure 18: Photo of the deployed AstroMesh reflector (image credit: Astro Aerospace)

Hosted TDPs (Technology Demonstration Payloads: LCT, Q/V-band transponder, Star Tracker, AEEF)

As a cost-effective way to deploy new services, validate new technologies, give them 'flight heritage' in space and introduce them in the commercial market, the concept of 'hosted payloads' offers a win-win-win solution for operators, industry and public institutions alike. [37) 38)]

Hosted payloads benefit from available capacity on commercial satellites to accommodate additional transponders, instruments, or other applications that have to be operated in space. Partners share the satellite platform. This arrangement takes less time and money to implement, allowing advances in satcom technologies and services and new businesses to grow. This concept has also been referred to as 'piggybacking', 'hitchhiking' or secondary payloads.

Through ARTES, ESA has supported a number of hosted payloads over the years. These include the launch of the Skyplex processor payload on the Hot Bird 4 satellite of Eutelsat (launch Feb. 27, 1998 into GEO), followed by AmerHis on Amazonas 1 (AmerHis is the first operational regenerative, onboard processing, satellite switching system in the world, launch August 5, 2004). AmerHis has enabled Hispasat (Spanish telecommunications satellite service provider) to provide high-performance interactive multimedia services on its four Ku-band coverage zones: North America, South America, Brazil and Europe. The AmerHis system is an innovative solution of satellite broadband mesh communication based on a regenerative DVB-S/DVB-RCS processor.

Figure 19: Photo of Alphasat during encapsulation on July 15, 2013 (image credit: ESA,Ref. 38)

Legend to Figure 19: Alphasat carries a quartet of test technologies on its side: Q/V-band transponder, AEEF,Star Tracker, and LCT. The first and last of these are particularly conspicuous due to their covering of gold-coloured foil.

LCT (Laser Communication Terminal - TDP1):

Developed by Tesat Spacecom (Germany) and Ruag Space (Switzerland) with funding from DLR (German Space Agency) and the Swiss Space Office, and coordinated by ESA, this TDP (Technology Demonstration Payload) is a data relay mission to link observation data from LEO observation satellites towards a ground station through the geostationary Alphasat. The data-relay link between LEO and GEO will enable direct downloads from Earth observation satellites to small terminals, allowing for example, rescue workers to see near-realtime satellite imagery of the region where they are working. The LCT instrument is of TerraSAR-X, NFIRE (DoD) and TanDEM-X mission heritage. [39) 40)]

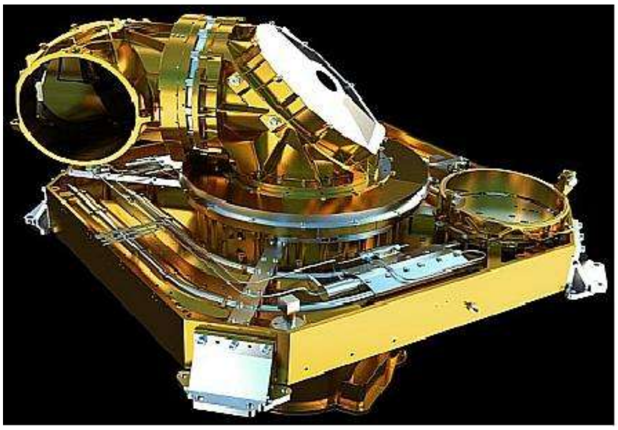

Figure 20: Tesat Spacecom 2nd generation LCT instrument showing the space side with hemispherical coarse pointing unit (image credit: Tesat)

The LCT provides a 2 Gbit/s bidirectional data link between the LEO satellite and the Alphasat I GEO satellite using laser diode pumped Nd:Yag (neodymium-doped yttrium aluminum garnet) crystal lasers transmitting infrared light at an ultrastable wavelength of 1.064 µm.

The LCT includes two major functions: to relay Earth observation data from LEO satellites (for example, Sentinel-1), and to verify the bidirectional optical link (experiment results, such as error counts, sensor data, etc., are transmitted via Alphasat telemetry to the ground for evaluation).

The major advantage of laser communication terminals compared to conventional RF payloads is their very high data rate, and this is the first time that such an optical LEO-to-GEO link will be verified in orbit. This TDP is a precursor of an operational optical communication system that will be used for ESA's EDRS (European Data Relay System).

The satellite laser terminal acquires the very weak signal from the optical beam of an optical counter terminal, which may be up to 50,000 km away. Once acquired, the data transmission between the two laser terminals (LEO and

GEO) starts. Considering that LEO satellites travel at ~ 8 km/s (28,000 km/h), and the GEO satellite at about 3 km/s (11,000 km/h) in different directions, accomplishing this link is indeed a big challenge.

The received data are then downlinked via the Ka-band transmitter to the DLR ground station. More than ten LEO-to-GEO links per day in the first years of operation are expected.

Optical link	LEO-GEO full duplex communication
Data format	1064 nm, BPSK (Bi-Phase Shift Keying) modulated, homodyne
Data rate	2.8 Gbit/s (1.8 Gbit/s user data)
Link distance	> 45,000 km
BER (Bit Error Rate)	10^{-8}
Optical transmit power	2.2 W
Telescope diameter	135 mm
LCT instrument mass, power	53 kg, 160 W
Instrument size	0.6 m x 0.6 m x 0.7 m

Table 3: Key design features for LCT LEO-GEO relay [41)]

On May 3, 2012, the laser terminal arrived in Toulouse, France, from Backnang, Germany, and has now been bolted to the Earth-facing part of Alphasat. [42)] [43)]

The LCT block diagram is shown in Figure 21. Major changes are: For the 2nd generation LCT an off-axis telescope is chosen, the optical power amplifier is changed to a 5 W device, the receiver is optimized for a user data rate of 1.8Gbit/s. For GEO applications, the electronics were redesigned to operate the adapted devices and to match with the GEO radiation environment for 15 years of continuous service. The thermal system is improved, the mechanics scaled for the bigger units. [44)]

LCT generic design/qualification approach: The LCTs are built such, that the LCTs for GEO and LEO application are same for its units design and their qualification. The GEO and LEO LCTs have identical optical space interfaces with same performance. For adaptation of the generic design to the 2nd generation LCT to S/C application, only the spacecraft interface related items (e.g. bus voltage, TM/TC interface and thermal interface) are modified. In Figure 22. the Alphasat LCT is seen with its customized thermal interface for the Alphasat spacecraft.

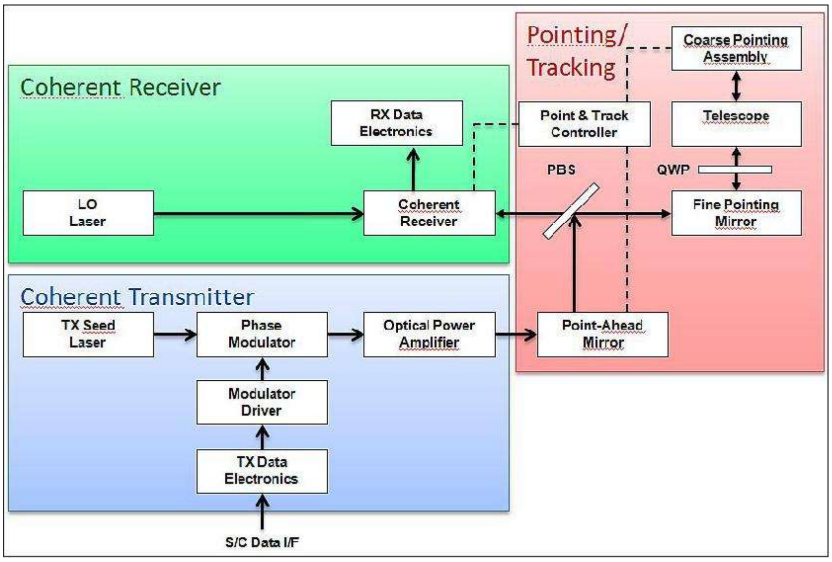

Figure 21: Block diagram of the LCT instrument (image credit: Tesat Spacecom)

Figure 22: Alphasat LCT, equipped with MLI, with an Alphasat specific thermal Interface, mounted in its

transportation frame (image credit: Tesat)

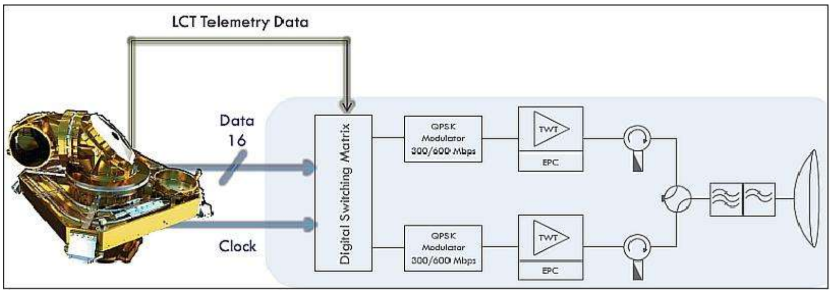

Figure 23: Alphasat data relay payload (image credit: Tesat) 45)

Q/V-band transponder payload (TDP5) / Aldo Paraboni Payload:

The Q/V-band payload, developed by TAS-I (Thales Alenia Space-Italia) and Space Engineering, has the objective to assess the suitability of this millimeter-wave band for future commercial applications. The propagation package will allow beacon measurements throughout Europe at Ka-band (19.704 GHz) and Q-band (39.402 GHz). The TDP5 payload is funded by ASI (Agenzia Spaziale Italiana). [46) 47) 48) 49) 50)]

In the summer of 2013, ASI decided to rename the Q/V transponder payload to **"Aldo Paraboni Payload"** in memory of the late Professor Aldo Paraboni, who died on April 13, 2013 and who had dedicated his academic life to space telecommunications research in all ASI projects. [51) 52)]

Advantages and today's limitations of Q/V-bands: [53)]

• Larger bandwidth

• Smaller antenna for fixed gain

• Higher gain for fixed antenna

• Enhanced directivity for spot beams systems

• Increase of atmospheric impairments

• Research activities needed

• Different design approach: a) FMT(Fade Mitigation Technique), b) lower QoS (Quality of Service).

Given the very strong atmospheric fading that can be experienced at Q/V frequencies, the communication experiment is aimed at demonstrating the capability of IFMT (Interference and Fading Mitigation Techniques), and site diversity in improving the link quality in a real Q/V band satellite link.

In 2009, ASI (Italian Space Agency) invited Austria to join the TDP5 experiments. Thanks to the support by the Austrian Aeronautics and Space Agency, it was decided that a Q/V-band ground station will be established in Graz to be able to carry out joint communications and propagation experiments with the Italian partners: ASI, Space Engineering, Politecnico di Milano, and Università Tor Vergata of Rome. As a consequence of these agreements, it was decided to redirect the third beam of the Q/V-band payload to be centered over Austria. Joanneum Research and Graz University of Technology (TU Graz) are the Austrian partners in the Q/V-band payload preparing for communications and propagation experiments.

The main goal of the communications experiments is the investigation of **ACM** (Adaptive Modulation and Coding) techniques. At millimeter-waves the propagation effects can be very significant. A conventional system design with large fade margins is impractical, as this leads to high EIRP and G/T figures for the ground stations resulting in unacceptable costs. Fade mitigation techniques by adaptive coding and modulation offer a cost-effective solution to this problem.

In the framework of several ESA activities a meshed VSAT system has been developed which uses an advanced MF-TDMA demand assignment access scheme and an adaptive modem and Turbo codec. The synchronization algorithms for the modem have been optimized such that the modem can operate at a very low signal/noise ratio. This platform is ideal for the ACM experiments. The propagation studies and measurements will provide the data for the fade depths, fade slopes and scintillation effects. Based on the measurement results, the ACM algorithms will be optimized and verified in the communications experiments.

The block diagram of the Alphasat Q/V-band transponder is shown in Figure 25. The payload configuration can be seen in Figure 26. The two antennas have a diameter of 35 cm x 42 cm. The nominal output power of the transponder is 5 W at Q-band.

Figure 24: Photo of the Q/V-band communication repeater - also referred to as QVCA (image credit: TAS-I)

The **QVCA** (Q/V-band Communication Antenna) service area is composed of 3 ground stations. The beam centers have been defined for communications with three ground stations located at:

1) IT1: Tito Scalo (40º35'55" N, 15º43'23" E), in southern Italy

2) IT2: Spino d'Adda (45º24' N, 9º29'E), in northern Italy

3) EU1: Graz (47º05'07" N, 15º27'54" E), Austria

The transponders can be operated in different configurations: cross-strapped or loop-back (Figure 26). In the cross-strap mode, any two beams can be interconnected, leaving the third beam idle. The space-to-Earth center frequencies are 37.9 and 38.1 GHz.

The maximum EIRP of the transponder is 39 dBW, when remaining in the linear mode. The polarization is linear vertical to take advantage of the fact that the vertical polarization is less affected by rain fade than the horizontal plane. The Earth-to-space frequencies are 47.9 and 48.1 GHz. The figure of merit (G/T) of the transponder yields 4.4 dB/K (taking into account the spacecraft movement). A transponder channel bandwidth of 10 MHz is available.

Since the Q/V-band payload is a secondary and an experimental one, the EIRP and G/T are comparatively low, requiring relatively powerful ground stations.

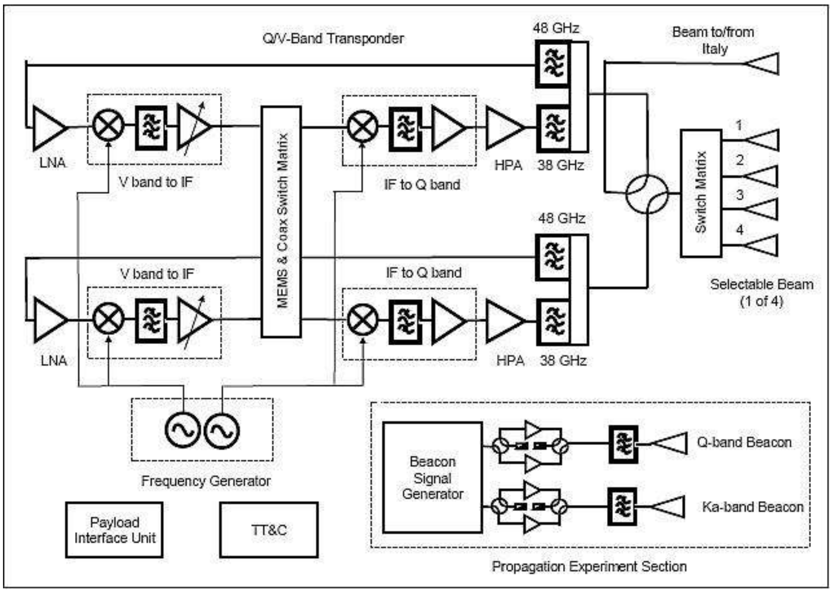

Figure 25: Alphasat Q/V-band payloads block diagram including propagation section (image credit: ASI)

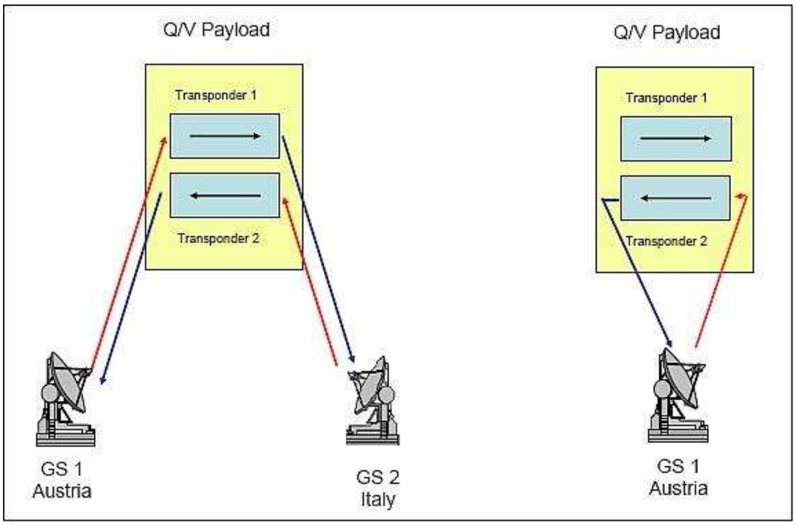

Figure 26: Modes of operations: Cross-strap mode (left), Loop-back mode (right), image credit: TU Graz

The block diagram of the ground station is shown in Figure 27. VHL (70/140 MHz) as well as L-band interfaces will be provided for maximum flexibility. The 70/140 MHz signal will be upconverted to L-band by a converter unit. In a second stage, the signal will be translated to the transmit frequency of 47.9 or 48.1 GHz and fed to a driver amplifier. Its output drives the HPA (High Power Amplifier). At the output of the power amplifier, a remote-controlled waveguide switch connects either to the antenna or a dummy load. Prior to the dummy load, a test signal is available via a 40 dB coupler which can be connected to a spectrum analyzer, a counter or the test translator, converting the V-band signal to Q-band.

Since only a single polarization is used (vertical), no ortho-mode transducer is required. However, a high-performance diplexer is needed. At the V-band port, the HPA is connected, whereas the LNA is directly attached to the Q-band port. At its output a coupler or switch allows to feed in the test translator output signal, when the station is in test mode. This configuration avoids degrading the system noise figure by a coupler or waveguide switch at the LNA input. The amplified Q-band signal is down-converted to L-band where it is directly available for L-band communications systems. If terminals with 70/140 MHz interfaces have to be used, a second down-converter from L-band will be utilized.

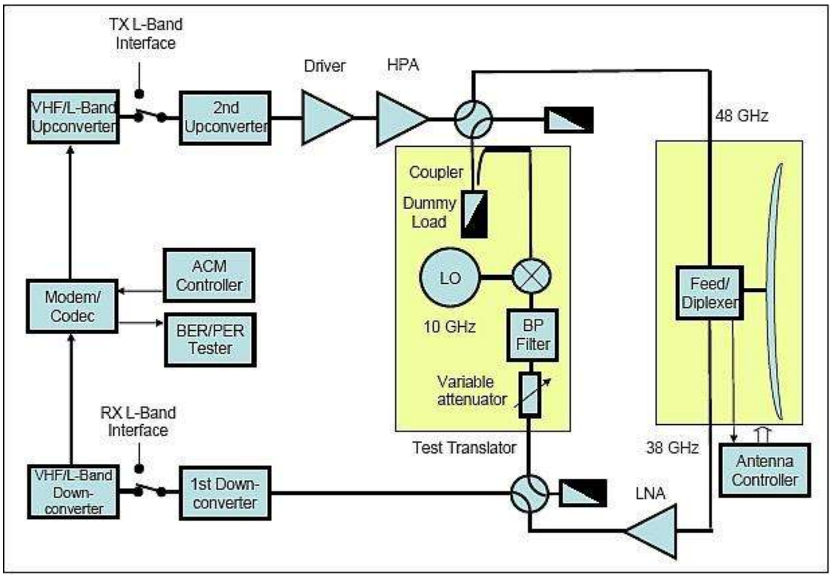

Figure 27: Block diagram of the Alphasat ground terminal (image credit: TU Graz)

The tracking system will be either monopulse or step-track depending on the antenna size which will be finally chosen. In principle, program track could be used as well, but this prerequisites excellent-quality and up-to-date Kepler elements.

The propagation receiver, which has to measure a cross-polar Q-band beacon and a vertically polarized Ka-band beacon will be connected to a separate co-located antenna. This avoids a very complicated and expensive feed and front-end. This decision was supported by the fact that the already well advanced beacon receiver project will get its own antenna with tracking from ESA.

Figure 28: Overview of the Q/V-band ground stations in the TDP5 payload (image credit: ASI)

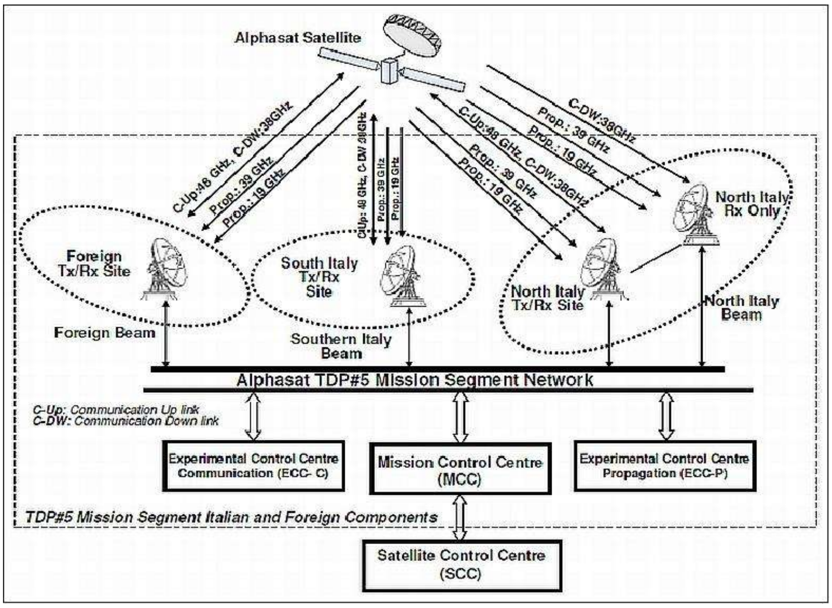

Figure 29: Alternate view of the TDP5 ground system (image credit: Space Engineering S.p.A., ASI) [54)]

• TDP5 features two fully redundant beacon transmitters operating at Ka-/Q-band. The Ka-band beacon at 19.7 GHz covers Europe and North Africa (Figure 30). The polarization is linear vertical. The Q band beacon at 39.4 GHz covers Europe with a maximum antenna gain over Milano (Figure 31). The Q-band beacon polarization is linear NW-SE (45° tilted). Table 4 summarizes the Alphasat beacon characteristics. [55)]

Parameter	Ka-band	Q-band
Frequency	19.701 GHz	39.402 GHz
Polarization	linear vertical	linear tilted 45º
Antenna boresight	32.5º N, 20º E	45.4º N, 9.5º E
EIRP (Effective Isotropic Radiated Power)	19.5 dBW	26.5 dBW

Table 4: Main characteristics of Alphasat TDP5 beacons

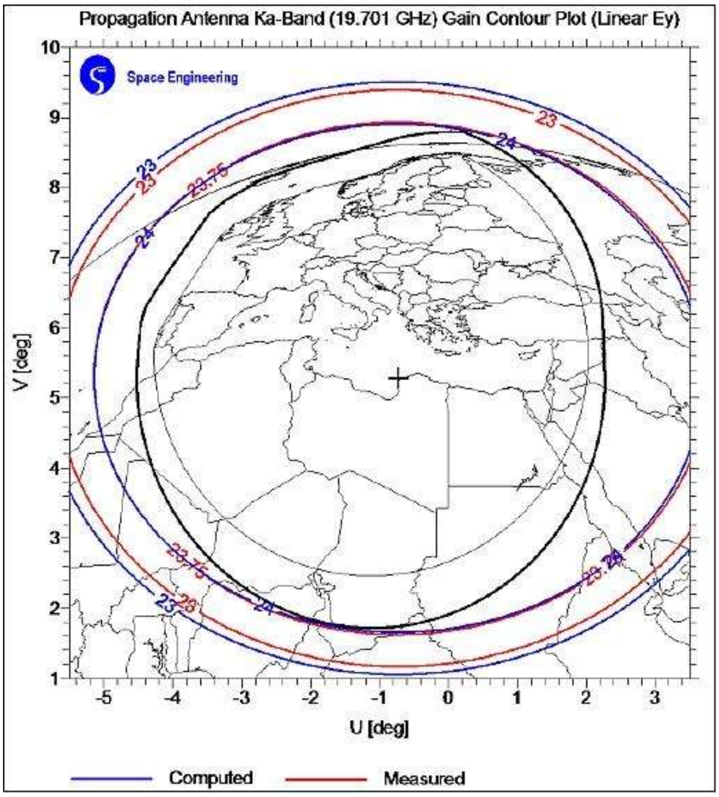

Figure 30: Alphasat TDP5 beacon coverage of the Ka-band, 19.701 GHz 56)

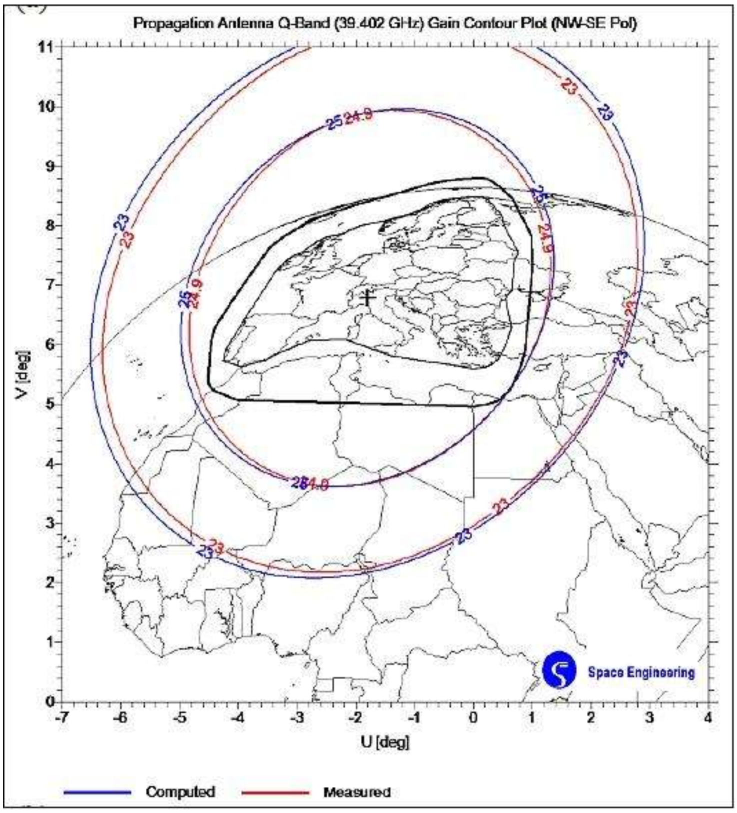

Figure 31: Alphasat TDP5 beacon coverage of the Q-band, 39.402 GHz

Star Tracker (TDP6):

Developed by Jena Optronik GmbH (Germany), the **Astro-APS** (Active Pixel Sensor) star tracker is included to gain early flight heritage on this new product. It is capable of very accurate and autonomous attitude acquisition. The sensor is highly resilient to the radiation experienced in geostationary orbits. 57) 58)

Figure 32: Photo of the Astro-APS star tracker (image credit: Jena Optronik)

Star trackers are used for attitude control of current generation communication satellites. By using stars as reference points, star trackers are help to make sure that a satellite keeps in the same position and points in the right direction. The higher the accuracy, the better a satellite can operate and spend less fuel, allowing a longer life in orbit. A star tracker can be heavily influenced by the radiation and sunlight. Jena Optronik's new generation of star tracker offers higher precision.

The Astro-APS uses the most radiation hard CMOS Active Pixel Sensor on the market, the STAR1000. Each pixel has an individual readout, thereby avoiding "blooming" of charge over to neighboring pixels. This improves performance with bright objects in the field of view, e.g. the moon. The centroid calculations are done on the same integrated circuit resulting in tracking rates, e.g. 10 Hz, that are much faster than CCD-based star trackers. Built-in software algorithms automatically identify and compensate for anomalies such as white spots. A Peltier cooler is included. The star sensor is a single unit with camera head, electronics, and a shorter baffle than on CCD-based star trackers.

Instrument size	154 mm x 154 mm x 231 mm	Including baffle
Instrument mass (sensor + baffle)	1.980 kg for GEO mission 18 years [MIL 1553B, 100 V power supply]	1.500 kg for LEO missions [RS 422, 5 V power supply]
Optical design Lens APS CMOS Detector APS Type	 Refractive (aperture ∅ 36 mm, f=1.2) resolution 1024 x 1024 pixels HAS (High Accuracy Startracker), rad tolerant	 focal length 43.3 mm active Peltier cooling STAR 1000 (rad hard)
Operational temperature range Non-operational temperature range	-30ºC to +60ºC -40ºC to +70ºC	
FOV (Field of View) Attitude accuracy Attitude accuracy (bias error) Attitude re-acquisition Attitude acquisition Slew rate Sampling time Straylight	20º (circular) < 1 arcsec [1σ] x y-axes < 5 arcsec x y z-axes < 2 s ["lost in space"] < 10 s [after switch-on "lost in space"] 0.3º/s [full performance] commandable 33 ms to 1 s [including tracking & attitude determination] Sun: 26º [half cone], Earth: accepted in FoV	 < 8 arcsec [1σ] z-axis over full temperature range < 0.2 s [with a priori information] < 3º/s [operational, "lost in space"] Moon: full performance
Data interface	MIL-STD-1553B, RS422	SpaceWire

Table 5: Performance of ASTRO-APS

ASTRO-APS qualification:

The ASTRO-APS star tracker of Jena-Optronik GmbH provides autonomously high accurate 3-axis attitude information with regard to the J2000 inertial reference frame and 3-axis angular rate measurements of the spacecraft.

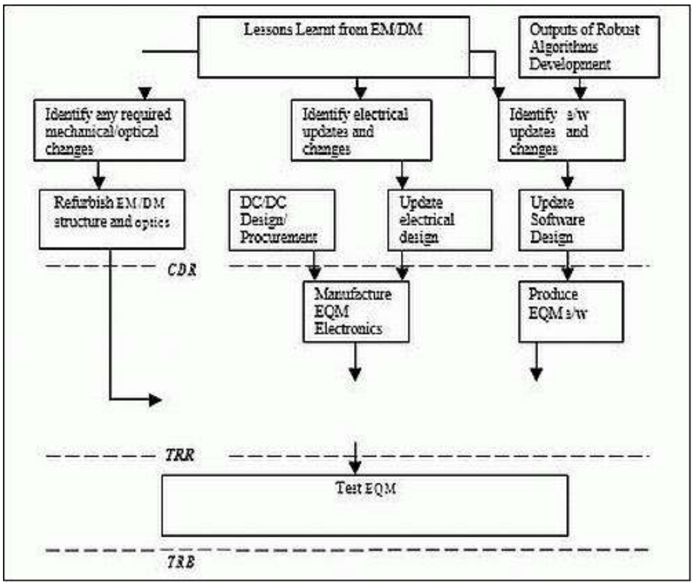

Figure 33: ASTRO-APS Star Tracker qualification project plan (image credit: Jena-Optronik, ESA)

The key-issues addressed in the scope of this qualification are the following:

- Redesign of the electronics from the EM configuration to the EQM

- Redesign of the S/W according to lessons learned from the EM tests and implementation of advanced acquisition algorithms

- Re-work of the EM mechanical structure and optics for the usage in the EQM (if necessary) and optimization of APS detector cooling

- Procurement of the DC/DC-converter

- Surface Mounted Technology (SMT) Process Verification

- Manufacturing, Assembly and Integration of the star tracker unit including baffle

- Qualification test campaign of the star tracker including baffle.

AEEF (Alphasat Environment Effects Facility - TDP8):

The AEEF is designed and developed by the EFACEC group (Portugal) in cooperation with the University of Aveiro (Portugal) and DAS Photonics (Valencia, Spain). The objective of AEEF is to test electronic components and solid-state materials in the radiation environment of a geostationary orbit. An energy selective particle spectrometer measures these radiation levels in parallel (Ref. 37). [59] [60] [61]

AEEF is comprised of a number of different elements measuring specific environments and effects together with dedicated hardware for data storage and interface to the spacecraft. The environments monitored include:

• High energy radiation (from the radiation belt, solar flares and cosmic rays)

• Low energy electrons

• Micrometeoroids and debris.

Additionally, AEEF includes a Component Technology Test Bed to investigate the effects of radiation on components (particularly of interest to the Alphasat payload). The following effects are monitored:

• Single event effects (e.g. single event upsets, single event transients)

• TID (Total Ionizing Dose) degradation (specifically of interest in the electron rich Alphasat environment)

• DD (Displacement Damage) to optoelectronics and detectors, and radiation background in sensors.

The objectives include full validation of hardening methods used in design, validation of new testing and analysis methods and demonstration of novel EEE (Electrical, Electronic and Electromechanical) component technologies. Additionally the validity of ground-based testing compared to in-flight results will be studied.

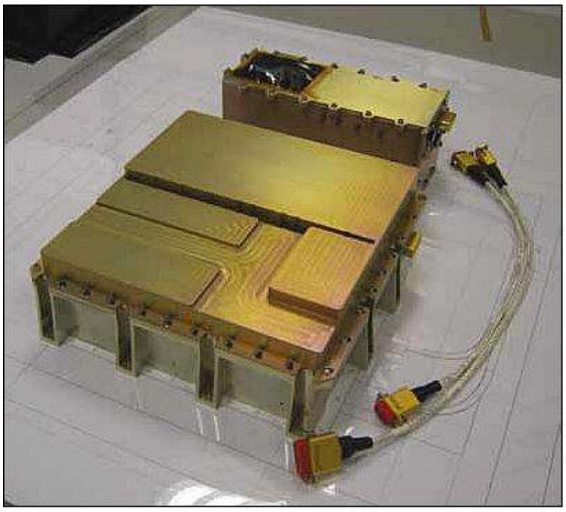

Figure 34: Illustration of the AEEF assembly (image credit: ESA, EFACEC)

AEEF includes two technology demonstration boards: one SIOS (Sistema de Interconexiones Ópticas para Satélites) optical link demonstration board and one GaN (Gallium Nitride) board. The SIOS optical link demonstration board will include 4 low data rate (1 Mbit/s) and 4 medium data rate (100 Mbit/s) optical links, with different power budgets among them to check the impact on each power output in flight conditions. The experiment will be running during 3-5 years, testing their power consumption and monitoring BER in real flight conditions. 62) 63)

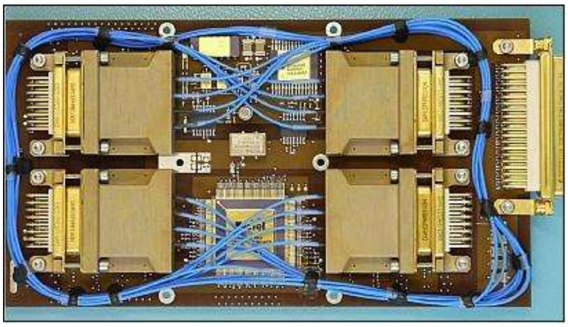

Figure 35: EQM (Engineering Qualification Model) of the SIOS experiment for AEEF (image credit: DAS Photonics)

GaN (Gallium Nitride): GaN is currently used in terrestrial applications such as LEDs (Light Emitting Diodes) and radio frequency applications up to 60 GHz. It provides several advantages compared to more conventional semiconductor technologies based on Silicon and GaAs (Gallium Arsenide). The most important feature is its high breakdown voltage (10-fold when compared to Si) allowing for compact high speed devices with significantly increased output power. For space applications, its reduced sensitivity to cosmic radiation is of particular importance and a decisive advantage over Si devices. 64)

The AEEF assembly has a mass of 10 kg, a total power consumption of < 25 W EOL, and a nominal lifetime of 3 years. AEEF will be monitored at Inmarsat, London and at the ESA TDP Coordination Office (Ref. 61)).

Alphasat I-XL GS (Ground Segment) Overview:

The Alphasat I-XL satellite is developed through a Public Private Partnership (PPP) between Inmarsat and ESA. Alphasat will be integrated into the Inmarsat satellite fleet to provide mobile satellite communications services for users in the maritime, land and aviation sectors. It will provide coverage over Europe, Asia, Africa and the Middle East.

The Alphasat services and ground segment developments are developed in partnership with ESA as part of the PPP with Inmarsat. Those activities cover the design and development of new services, ground segment infrastructure, user terminal technology and applications with the aim to fully exploit the capabilities of Alphasat.

The Alphasat spacecraft is operated from the Inmarsat SCC (Satellite Operations Center) in London. All systems required for the realtime monitoring and control of the flight segment are located at the Inmarsat satellite (fleet) control center.

Given the very different nature of the commercial primary mission of the satellite, and the scientific, experimental mission of its hosted payloads (the TDPs), an ad-hoc concept of operation has been devised. This concept needed primarily to consider that the commercial operator of the satellite had to include the new satellite into its fleet of multi-families (from different makers) satellites, controlled via a UMCS (Unified Monitoring and Control System). The operations concept for the TDPs has been therefore designed to interface with the existing ground segment systems minimizing (or avoiding wherever possible) the need for modifications. The resulting concept aims at making the activities of the TDPs de-coupled from, and transparent to the commercial operations execution. This has been achieved by establishing an upstream coordination and interfacing entity, capable of providing the required exchanges of data for in-flight operations, while minimizing the impact in the Inmarsat satellite control center, both for the operations planning and the TDPs monitoring functions. 65)

• On the monitoring side, a relatively straightforward solution is identified; with the implementation of a **"black-box"** approach to TDPs operations, based on a non-interference basic rule.

• On the controlling side, the same approach is complicated by the need to provide consistent and consolidated operational requests to the commercial operator in line with the operations execution products (TC sequences, procedures, etc) validated in cooperation with the satellite manufacturer.

The systems required to process the ESA **TDPs** (Technology Demonstration Payloads) and platform TM packets are located at the TDP OCs (Operation Centers) . The telemetry is monitored for limit transgressions, and processed to produce the scientific products. Archiving of the TDP and platform (as available to the TDP) telemetry is performed at the TDPs OCs.

Figure 36 illustrates the overall TDPs ground segment, including the Inmarsat SCC. The various TDP OCs and related systems are color-coded to highlights the involvement of other actors, notably for TDP1 (in red) and TDP5 (in yellow) for the experimental exploitation of the corresponding hosted payload.

Due to the different nature of the hosted payload, their experimental requirements, constraints, corresponding plans, and the need to coordinate and de-conflict the operations requests of the TDPs amongst themselves and with respect to the platform activities, it was decided early in the operations preparations to provide a single operations interface to Inmarsat.

Although a direct data interface link does exist for TM streaming and monitoring access between Inmarsat and the TDPs, the TECO (TDPs ESA Coordination Office) provides this single point of contact between the Inmarsat SCC and the TDP OCs, called MCC (Mission Control Center) for TDP1 and TDP5. [66)]

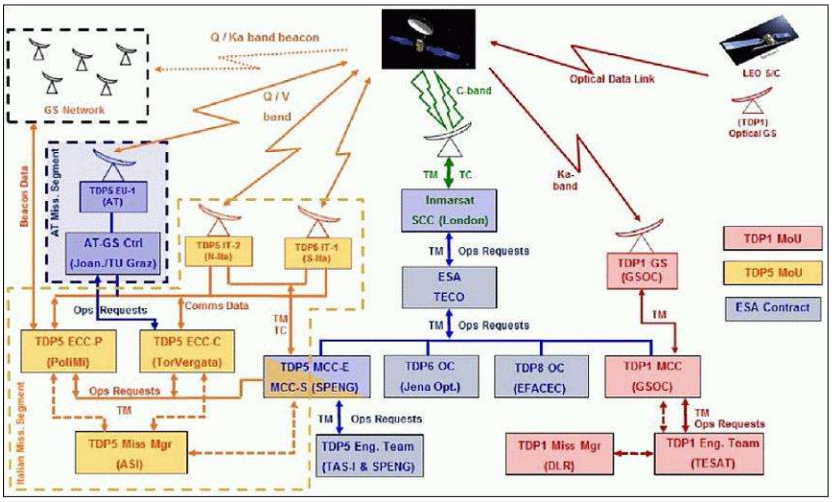

Figure 36: Alphasat TDPs overall Ground Segment (functional) architecture (image credit: ESA, Inmarsat)

Inmarsat has prepared a TDP operational data ICD (Interface Control Document), detailing the required format of all operational products to be transferred between INM (Inmarsat) and the TDP Operations Centers, e.g. weekly operations requests and OEMs (Orbit Ephemeris Messages). Similarly, an ESA provided ICD regulates the operational interface between the TDP OCs, the TECO, and INM.

TDPs operations concept and general rules:

The following principles were agreed between Inmarsat and ESA as the working basis for the hosted payload operations, responding to general operations requirements, as well as specific requirements for particular phases or scenarios of the Alphasat and TDPs missions. The resulting operations concept aims at satisfying the three main drivers of the Alphasat hosted payload mission:

- Fulfillment of each TDP experimentation plan

- Non-interference with the Alphasat (commercial) mission objectives

- De-coupling from and transparency to Alphasat (commercial) operations.

• The TDP operations execution only is performed by Inmarsat. This is driven entirely by the inputs and supplementary information received from the satellite manufacturer (procedures, etc), TDP supplier (e.g. procedure's parameters values) and ESA (e.g. consolidated TDP operations requests and schedule).

• No TDP operations engineering activities are performed by Inmarsat, i.e. no TDP contingency recovery actions are defined, and no analysis of TDP performance or health are performed by Inmarsat. This implies that the initial conditions for the execution of all operations shall be verified in (at the beginning of) the corresponding flight operation procedure.

• The downlink data and telemetry budget, and therefore experiment execution, is shared between the TDPs and operational requests are managed at a top level by ESA.

• To obtain a seamless integration of the TDPs operations into the Inmarsat fleet operations, the standard operations interface products already in use at Inmarsat for operations automation have been used. Although a certain level of tailoring has been found necessary, the flexibility of the pre-existing system has permitted a simple customization, with most changes deriving from the need to agree on common naming conventions and definitions.

• It has been decided, on the planning side, to follow a weekly incremental cycle. This permits to harmonize the TDP operations with the satellite housekeeping cycles (notably, station keeping maneuvers). The TDP operational requests are thus delivered weekly to Inmarsat, where the requests are integrated with the spacecraft and prime payload operations scheduling.

• Operations requests are in the form predefined "tasks", defined via the corresponding procedure IDs, parameter and timing values. All procedures, in their validated and executable form, are located at the Inmarsat Operations

Center and are referenced for operational use only by ID via the tasks invoked. Command IDs are held within these procedures and are constructed for execution by the MCS using the information in the SRDB (Satellite Reference Database). Procedure parameters to be used at execution time are identified by the PPF (Procedure Parameter File) IDs.

• Inmarsat responds with the spacecraft schedule subsets, as appropriate for the TDPs, which will confirm, or otherwise, the inclusion of the TDP operations in the spacecraft activity schedule. In some cases the TDP operational requests may not be included in the spacecraft activity schedule due to ongoing operational, maintenance or contingency activities. The rejected operational requests are notified to the parties involved.

Commissioning and IOT (In-Orbit Test):

• Initialization and commissioning activities were performed per TDP in pre-scheduled periods according to the approved overall Commissioning plan.

• With the exception of the switching ON of one of the hosted payload (TDP6), that took place as soon as possible after launch, the initialization of the TDPs started after the Platform and Prime mission had been fully initialized and were coordinated with the satellite commissioning activities. Although it had been (naturally) agreed that these latter took precedence over TDPs activities, no conflicts were encountered throughout the exercise.

• All Initialization and Commissioning procedures were provided by the TDP suppliers, communicated to the satellite manufacturer, and validated in the spacecraft context prior to delivery to Inmarsat. These included contingency recovery procedures for the known failure scenarios, aiming at bringing the TDP into a safe (OFF) status for further investigation without impacting the overall flight plan (subsequent commissioning activities timeline).

• TDP, ESA and ADS (Airbus Defence and Space) representatives were present, where necessary, at Inmarsat, depending on the complexity of the operations. A dedicated support space allowing access to realtime data was made available to the TDP representatives. Operations were conducted in real-time allowing insertion of parameters after near-realtime data processing by the TDP supplier. Beyond TM monitoring facilities, all software tools required for data processing by the TDP team was provided by the TDP suppliers.

It shall be noted that the Commissioning Plan and sequence of procedures for the TDPs to be included in Alphasat IOT phase were frozen at FAR (Flight Acceptance Review). Given the nature of the hosted payload ("technological demonstrators") the plans were designed on-purpose following an atomized approach, to permit single and self-standing building blocks to be rearranged according to possible timeline changes driven by the satellite or the concerned TDP in-flight needs. Although no changes were dictated by the flight segment, this proved extremely useful to accommodate few re-schedule needs (arising from events affecting notably the TDPs GS or data interpretation/calibration delays).

Nominal operations:

• The Alphasat TDPs nominal mission planning cycle is based on a 7 day cycle with the possibility for parameter inputs from the TDP operations centers on a daily basis.

• Notwithstanding the mode dependency for the provision of attitude data from the TDP6 star tracker to the TDP1 laser communication terminal for pointing purposes, the TDPs are designed with minimal inter-TDP operational constraints, such as power or thermal constraints. However, if any constraints exist between the operations of the TDPs, these will need to be checked and resolved before forwarding consolidated operations requests to Inmarsat. The ESA TDPs Coordination Office is foreseen to help the TDPs Operations Centers in the planning exercise, to avoid schedule conflicts, while the responsibility for the correctness and compatibility of the operations requests rests with the TDPs team.

• In case of breach at execution time of any of the budgets limitation (notably power or bandwidth), Inmarsat SCC can unilaterally interrupt (abort) the current TDP task execution, without previous notification. Notification of the event is given as soon as practicable.

• The objective at system level is to design the TDPs and their operations such that they are robust to inter-TDP constraints and conflicts. If conflicts are identified, the TECO planning system attempts to resolve them with the TDP operations centers, and ensure that the TDP requests received by Inmarsat will be conflict free.

Contingency operations:

• Inmarsat will not react to TDP anomalous conditions. The parameters monitored by the FDIR (Failure Detection Isolation and Recovery), will protect the TDP against all foreseen critical anomalies requiring a response time less than 2 weeks.

• The FDIR have a simple recovery action for the TDPs, e.g. switch off, so as to allow continuation of the Prime mission with no risk for the Prime mission performance. The ground is notified of the FDIR action and trigger conditions in the nominal telemetry and the information is provided to the TDP suppliers as part of the TDP telemetry and auxiliary data delivered via the nominal mechanism.

• Anomaly Review Boards are convened to review the causes of any anomalous TDP behavior and to assess the recommended actions. ESA, ADS and TDP supplier participate in the ARB and agree on the actions to return to nominal operations of the TDP affected. The recovery actions, procedures and any required computations and parameters have to be prepared and validated by the TDP supplier and ADS, and are submitted to Inmarsat for verification and acceptance.

• The TDP recovery operations are conducted via the nominal mission planning cycle or more quickly on a best effort basis by Inmarsat.

• In the case of recurring or known anomalies with defined TM profiles, Inmarsat will respond based on a clearly defined action recorded in ad-hoc created procedures if within existing resources (both pre- and post-launch) and on a best effort basis.

• In the case of an anomaly on the Alphasat platform or payload, Inmarsat has the right to suspend TDP operations without notice. TDP operations are usually suspended by the on-board FDIR in case of anomaly, but Inmarsat may also suspend the TDP operations from ground, by triggering the automated TDP switch off sequence or in accordance with a validated procedure, and suspending all further TDP operations from ground. Information on the time at which TDP operations are suspended are provided to the TDP operations centers but no further information are made available, as these are made available via the normal periodic provision of TM/TC/Event logs.

• A simple "Emergency Switch OFF" procedure has been provided by each TDPs, to be used by Inmarsat in the scenario described above, or as a further safety measure in case of an unforeseen anomalous behavior of a TDP (i.e. not covered by FDIR).

• In the case of toggling out of limits (OOLs), Inmarsat would raise an Anomaly Report and edit the limit in the database to prevent continuous system alarming. Action should be taken by the TDP operations center and ADS to either plan the appropriate recovery action, as part of the nominal planning cycle, or to update the limits in the next database update.

TDP decommissioning:

Similarly to the commissioning and IOT phase, decommissioning of the TDPs at the end of (their) operational life will be performed via an agreed ad-hoc plan, using bespoken pre-validated procedures.

TDPs Monitoring and Control:

The MCS (Monitoring and Control System) of Alphasat, including the TDPs flight segment, is managed by Inmarsat from the MCC (Mission Control Center) in London. Inmarsat have operational interfaces with all necessary operational elements, including the ground stations, the TDP operations centers and ESA. All operational versions of procedures and databases and all telemetry and telecommand data will be archived. The functional architecture (topology) of the Alphasat ground segment as applicable for the TDP operations is shown in Figure 37.

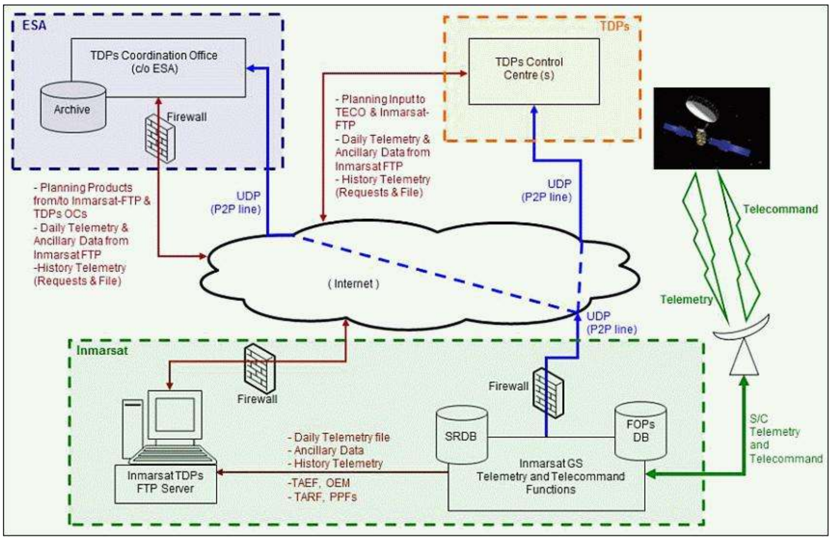

Figure 37: TDPs Monitoring and Control GS topological architecture (image credit: ESA, Inmarsat)

Figure 37 highlights the (near) realtime connection via UDP (User Datagram Protocol) stream of TM directly from the Inmarsat SCC (in blue), and the ftp based exchange of non real-time data both from off-line monitoring and control (planning) purposes (in red). Not shown in the picture is the NRT (Near-Realtime) TM monitoring system, based on the MCS server owned by TECO but based at INM.

The sole operations planning and control interface for Inmarsat SCC is to the TECO (TDPs ESA Coordination Office), while a direct data interface, coordinated for the TDPs by TECO, for the TM and NRT monitoring access to the TDP Operations Centers is established. Data exchange is performed through a ftp server, located at Inmarsat, and accessible by all parties via Internet, and a similar ftp server, located at TECO. Authorized users are able to access the ftp server via a secure login and user account VPN (Virtual Private Network). TM packets are distributed to TDP operations centers and ESA via UDP broadcast and are interpreted and archived by the operating system located at the users' site. In addition, a NRT monitoring facility has been implemented by providing remote access by TECO and the TDPs Operations Centers (OCs) to a dedicated server at Inmarsat running an ad-hoc configured version of the SCC/MCS (Satellite Control Center/Monitoring and Control System) I4S (Innovative Satcom Security System for Ships).

SRDB (Spacecraft Reference Data Base):

TDP telemetry and telecommands are contained in the SRDB. The SRDB will be populated by ADS(Airbus Defense and Space) using information supplied by the TDP suppliers. The SRDB is fully validated at satellite system level before delivery to Inmarsat.

The SRDB contains, where necessary, the relevant TDP limit checks, validity and pre- and post- execution check information, as required. It is agreed that TDP limits are for information only, and no actions are required from Inmarsat if limits are transgressed, given that all failure detection and isolation are handled autonomously on-board (i.e. all TDP failures requiring action are handled by the FDIR software).

TDP Monitoring and Data Management:

Three different ways of monitoring the TDPs are provided (as illustrated in Figure 38):

- UDP TM stream (packets)

- Daily products via FTP (File Transfer Protocol)

- Web-based connection to the dedicated MCS server.

Attitude information, within nominal limits, will be made available to the TDP operations centers using the nominal mechanism. The attitude may be raw/calibrated telemetry or the processed derived parameter. Outside nominal limits, no data will be available.

1) *UDP (User Datagram Protocol) TM Stream:* A realtime interface is available to provide, via UDP broadcast, to the TDP their own TM data (packets and parameters generated by the hosted payloads and downlinked in the satellite

TM stream), and a subset of selected platform telemetry parameters, pertinent for TDP performance evaluation and activity planning. The set of auxiliary data is agreed between ESA and Inmarsat, and filtering is performed at packet level by masking out the non-available parameter by substituting their value with a predetermined binary sequence.

To use the UDP stream, the TDP operations centers have to provide for extracting the parameters from the packets and performing any necessary processing. - In the case of an Alphasat anomaly, Inmarsat has the right to disconnect the near real time interface to the external operators.

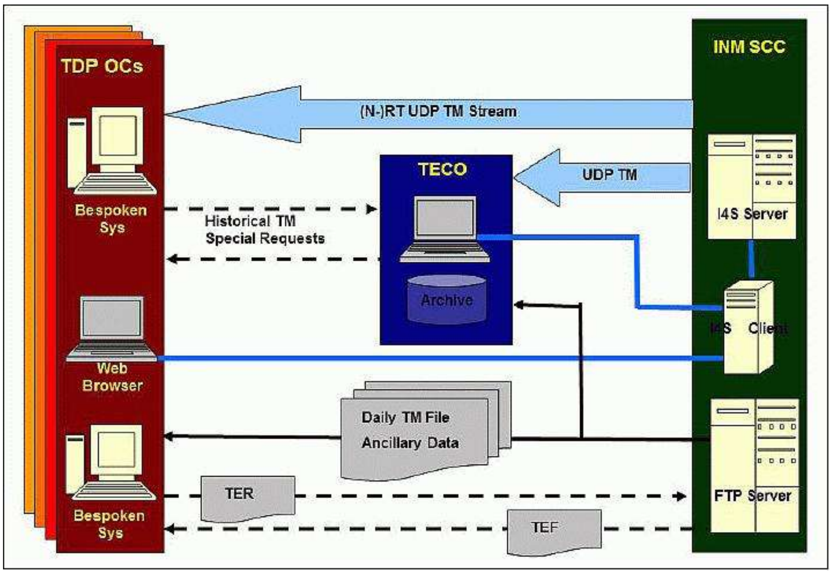

Figure 38: Alphasat TDPs monitoring (image credit: ESA, Inmarsat)

2) *Daily products via FTP:* Every 24 hours, the last 24 hours of TM are available on an ad-hoc INM ftp server, where they remain available for a limited period. In addition, the telecommand history filtered for the TDPs (and containing a pre-defined sub-set of relevant platform commands), information regarding database limit transgressions, and selected spacecraft generated events related to the TDPs, as relevant, etc. are uploaded to the server.

The non-TM information comes from the AWE (Alarms, Warnings and Events) log. Messages from procedures are also posted to the AWE and so could be used to provide complementary information to the TC history. Filtered operations logs containing TDP SRDB limit transgressions and TDP commands sent, are uploaded to the ftp server daily; any other messages to TDP Operations Centers may also be conveyed via this mechanism.

3) *Web-based connection to dedicated MCS server:* A dedicated MCS server is installed at the Inmarsat SCC premises, providing remote access via a COTS Web Browser to the monitoring facilities and the RT TM in the very same environment (and with the same MMI) of the actual Inmarsat "I4S" unified Monitoring and Control System used for the handling of its multi-family fleet of geostationary satellites.

Figure 39 shows the high level architecture of the provided system (customization of the general I4S MCS platform).

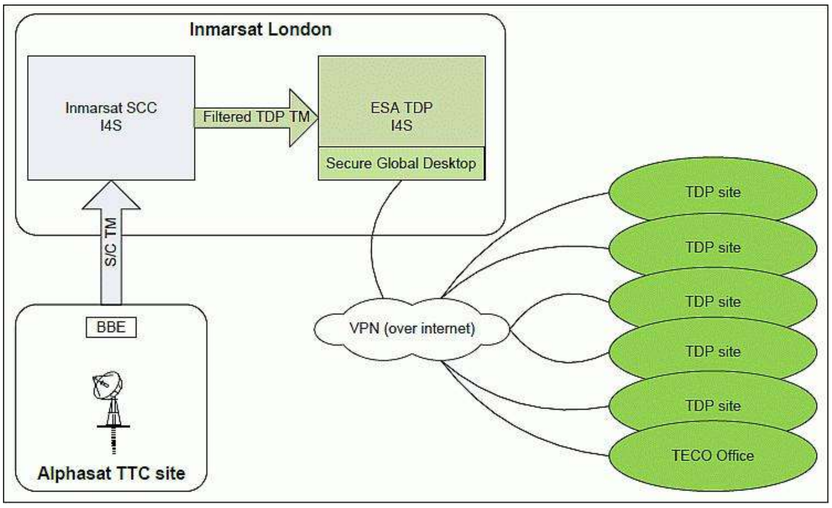

Figure 39: ESA (TECO) TDP I4S system architecture (image credit: ESA, Inmarsat)

The ESA TDP I4s system is a TM processing and archiving system which can operate independently of the Inmarsat System provided a (filtered) TM feed is supplied. In practice the TM feed will always come from the Inmarsat SCC via UDP ensuring uninterrupted data supply.

The SGD (Secure Global Desktop) software is in use to allow access to the I4S system, allowing a remote user to access the back office machines via a standard Web Browser interface (architecture used already by the Inmarsat SCC for remote access to their I4S system).

The following components are available in the TECO I4S server:

- System Services (handles system services execution)

- Telemetry Processing (decommutation, EU conversion, limit checking and data distribution)

- Archive (provides for raw telemetry and AWE archiving)

- Alarm, Warning and Events Manager (provides system activity monitoring)

- Retrieval (retrieves data from archives and plays data back)

- Client API (provides programmers' interface to telemetry and AWE's).

At client level, accessible to the external users (TDPs), the following client components are available:

- Alarms, Warnings and Events Display

- Out of Limits Display

- Telemetry Displays (JADE) for ANDs, plots and mimics.

Moreover, this server permits the retrieval via a TER/TEF (TM Extraction Request/TM Extracted File) mechanism of finite period of TM in parameter based, ASCII files.

TDP Commanding:

Nominal commanding is managed by the ground schedule execution system in line with the Mission Plan. The mission plan contains information on the operations to be performed over the week defined by references to pre-set "tasks" defined a-priori by specifying the composing procedure IDs, duration, and procedure execution times. The TDP commands held as part of the validated procedures are automatically released by the Inmarsat automated procedure execution system. It shall be noted that each procedure can be assigned a fixed execution start time or (as advisable) a start time and window of execution. In case of need for respecting an absolute time, a check of the time of execution needs be inserted in the procedure itself.

The spacecraft has the capability to either immediately execute the commands upon receipt at the spacecraft or insert them in the time-tag queue on board (OB TTQ). The nominal method for commanding is command release for immediate execution, from within procedures managed autonomously by the ground schedule execution system. TDP commanding shall only use time tagged commands (TTC) in the case of a hard requirement. Use of the OB TTQ is limited to specific operations that require a high commanding accuracy. These operations will require justification and shall be infrequent.

The procedures variables values are controlled through:

- ingestion of values from PPF (Procedure Parameter File)

- calculation within the procedure from values assigned in PPFs or telemetry

- manual setting

Parameter value assignment can be done only at run time. Nominally, interaction with the TDP procedures can only be done via PPFs. TDP PPFs must be delivered latest 2 hours before the actual procedure execution to the ftp server in the agreed format, and the corresponding task must have already been included in the schedule. The procedures support branching and the branching can be chosen based on telemetry or procedure variable values.

The Planning Cycle:

The Alphasat operations are based on a weekly incremental plan, and automated execution of the tasks scheduled. The TDPs activities are merged into the weekly schedule with the Inmarsat commercial and platform housekeeping activities. Figure 40 shows the TDPs weekly planning cycle, and how this is interfaced with INM planning exercise.

It shall be noted that the satellite position is maintained through a series of in and out of plane maneuvers performed following a 14 days cycle, with daily electric propulsion maneuvers compounded by bi-weekly chemical maneuvers. The corresponding orbit ephemeris data (OEM file) is produced weekly, 12 hours in advance of applicability time, and includes the consolidated predicted orbit for the next 7 days, and a preliminary orbit propagation for the subsequent 7 days (coarse prediction).

Each week on day 7, each TDP OC delivers to TECO the p-IOR (preliminary-Input Operations Request) based on the coarse OEM and preliminary platform activities knowledge (current OEM). The coarse OEM used by the TDP OCs may cover a period longer than the 14 days given in the Inmarsat provided OEM, and based on the requirement for the Alphasat satellite to stay within its orbital slot (±0.1º from the nominal longitudinal position). The p-IORs from all TDPs are made available to all TDP OCs to support the internal planning exercise leading to the production of the IOR (Input Operation Request).

Later the same day Inmarsat uploads to the Alphasat/TDP ftp server the TAPF (TDPs Activity Planning File), containing the relevant spacecraft activities and TDP operations availability window, and an OEM (Orbit Ephemeris Message) data file. A notification is sent via email to the TDP users that the new planning input products have been published and are available for download. Authorized users are able to download the data as required. The orbit ephemeris files contain orbit parameters, and derived orbit event files (eclipses, etc), covering the orbit propagated over 14 days, with the first 7 days consolidated, assuming all maneuvers are executed as planned, and the second week only preliminary.

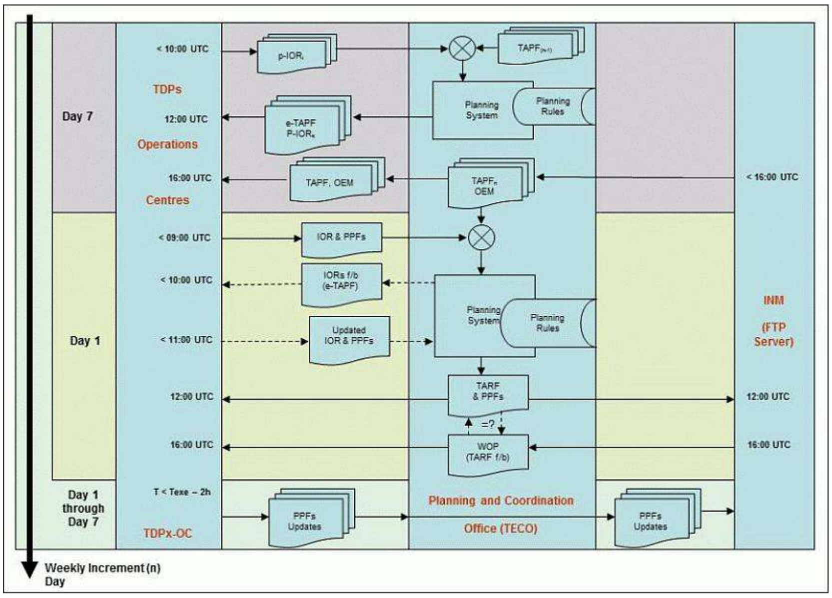

Figure 40: Alphasat TDPs Planning Cycle (image credit: ESA, Inmarsat)

• Periods when TDP operations may be affected or not permitted are provided in the TAPF, delivered to the server. Different operational activities may have different limitations on TDP operations. A distinction is thus made between those periods where TDPs could experience reduced performance (e.g. maneuvers), where no TDP related commanding activities are permitted, and where limitations exist on TDPs modes (either for all TDPs or on a TDP by TDP basis).

• Every week, on day 1 (the day following the distribution of the planning input files by INM) the TDP Operations Centers provide each an IOR (Input Operations Request) file and the PPFs corresponding to all requested activities to the TECO. The TECO merges the IORs from the different TDPs and check for possible conflicts both with respect to the satellite activities and for inter-TDPs operational constraints.

• In case of conflict, an ad-hoc conflict warning message is sent to the involved TDPs, to trigger a last iteration for the possible solution and delivery of the (conflict free) IOR and corresponding PPF files.

• On the same day, based on the final IORs and PPFs received, the TECO sends to Inmarsat the consolidated TARF (TDPs Activities Request Files) and the corresponding PPFs. The TARF covers 7 days of operations requests in the form of tasks IDs and with the values of all parameters associated to the corresponding procedures.

• If necessary, during each of the 7 days of the running increment, the TDP OCs can calculate new values for the parameters needed for the execution of each relevant planned procedure and deliver them to Inmarsat for upload as a PPF (Procedure Parameter File) at least 2 hours before the procedure execution. The PPFs are delivered directly to the Inmarsat server to be ingested into the procedure execution scheduler, and used for procedure execution at run time.

• In some cases the TDP operational requests may not be included in the spacecraft schedule due to ongoing operational, maintenance or contingency activities. The TDP OCs are in this case notified of any discarded operational request. It is intended that this situation be minimized through the provision of weekly permitted TDP operations time window information within the TAPF.

• There is a very tight window for TDP planning between delivery of the TARF files and the final weekly operations plan production by Inmarsat, incorporating the TDP operations plan requests, thus the system at TECO permits, as is suggested, that the TDP rough planning is performed in advance, perhaps based on a standard operational activity profile and coarse ephemeris derived from the Alphasat orbital 'box'. Execution times/windows are consolidated once ephemeris and availability windows are delivered to the server.

• Outside nominal operations of the TDPs, it is assumed that some calibration activities will be necessary. The calibration activities required during the routine operations phase shall be dealt with in the same way as the routine TDP operations; calibration requests shall be submitted for inclusion in the mission planning cycle, and the results of the activity, if required, will be evaluated off-line by the TDP supplier. Any parameter updates will be submitted, following evaluation, in the next mission planning cycle and may make use of PPFs.

Activities execution (and abortion):

At execution time, the TDP activities are passed to the automatic execution system, and the parameters corresponding to the procedures composing the activity are loaded from the corresponding PPF.

In case of a procedure step failure at run-time (eg TM check failure), the procedure is aborted and the operation abandoned. The TDP might be turned OFF via the contingency turn-OFF procedure. Contingency branching for the foreseeable step failures is included in the procedure. These procedure branches will lead the unit (TDP) to a safe and stable state (OFF if necessary) without requesting any human (Inmarsat controller) intervention.

As a matter of fact, all TDP procedure have been designed with:

• The provision of a "no operations" branch, by-passing all active steps and controlled by a PPF assigned "PROC_EXE" variable. Thus, in case for any reason the execution of a scheduled activity is not requested anymore, a simple PPF update permits to have a no-ops execution completely transparent to the Inmarsat SCC.

• A "controlled abortion" step, designed so that, in case of any failure encountered, the SCC operator shall jump to the execution of this step, ensuring a safe and stable final status to the TDP concerned.

Status and in-flight experience:

Since its launch in late July 2013, Alphasat has demonstrated to be an extremely reliable and kind host for the TDPs. The platform performances have been providing the "best case" scenario for the hosted payloads in terms of environment and constraints. In few occasions, the platform (and its operator) flexibility have actually permitted to fine tune and optimize the operational conditions for the hosted payload on need, after the first in-flight data were obtained and analyzed.

From a ground segment and operations perspective, beyond confirming the expected operability and performances post-launch of the TDPs, the LEOP and IOT experience has brought an increased confidence in the system, and reinforced the (necessary) awareness of having a clear and complete set of roles and responsibilities all covered, each properly assisted by the corresponding needed tools and procedures.

Since the formal entry in the nominal operations phase on January 1, 2014, more than 2000 (2169 as of April 4, 2014) activities for the TDPs have been scheduled, of which 89 in total (4.1%) were aborted. When an initial misconfiguration of the system that lead to the abortion of 78 procedures for is taken into consideration, the abortions figure reduces to 11 (0.5%). It shall be further noted that all the abortions were fully explained and understood, with none of them due to the activities planning or execution systems.

Few un-expected behaviors were observed (fewer than most of the actors involved possibly expected from a new platform, flying 4 technology demonstrators operated by 9 different companies and institutions, and using a new operations concept and system). All of these were successfully addressed by the operations concept and tools described above. The end-to-end system has actually shown the additional benefit of enabling the actors involved to exercise a high level of flexibility in the use of the various interfacing elements to perform operations outside the nominal scenario where convenient.

A special mention shall be made to the NRT monitoring system provided by the I4S. The project was initiated by ESA and Inmarsat as an additional, non-necessary tool for the monitoring and control of the TDPs complementing the use of the UDP TM stream and daily products. In particular (but not only) during the IOT phase, the system has gone well beyond the initial expectations.

As a matter of facts, the architecture of the system, with the very same Inmarsat I4S software team providing support, and no need for compilations of any of the system configuration products (notably the SDB), has proved a major advantage for the provision of a reliable and ubiquitous mean for RT and non-RT monitoring. Giving access in near real time (few seconds delay) to the very same TM stream accessed at the SCC, and in the very same environment, to all users, the execution of critical operations with a distributed supporting team (sometimes necessary in the TDPs experimental scenarios) have been made simpler and safer, if not simply possible at all.

Although not new to the concept of hosted payloads, the peculiar and disparate nature of the Alphasat TDPs (Technology Demonstration Payloads) brought about the need for Inmarsat and ESA to create a suitable operations concept and environment (Ref. 65)).

TDP1 Ground System:

TDP1 is a German research and development program, designed to proof the concept of a relay satellite system using an optical data transfer system for the satellite to satellite ISL ((Inter-Satellite-Link) connection. The downlink of the relay data will be performed using a Ka-Band RF downlink. This mission is commonly considered the precursor to the EDRS (European Data Relay System) constellation.

Hence, DLR/GSOC (German Space Operations Center) was tasked with devolving and implementing the ground system and providing an end-to-end data relay service from a pick-up point on the originating spacecraft, to delivery of the data to the end user on ground. [67)]

The overall system comprises of the optical terminal, LCT (Laser Communication Terminal), hosted on a geostationary spacecraft (Alphasat). In the case of TDP1, this satellite is not operated by GSOC, but by Inmarsat, which brings an additional player into the game, namely the ground system at GSOC, a dedicated antenna for the relayed data, an optical ground system and any combination of low- flying terminals.

According to the statement of work, the system should be capable of handling six optical terminals, one of which is aboard the relay spacecraft (Alphasat), one is an optical ground terminal, and the other ones are aboard low-flying objects (satellites or aircraft). A total of up to 22 optical links should be planned per day between any combination of two optical terminals.

The operational phase started after activation of the instrument on the geostationary spacecraft with calibration of the terminal, using the optical ground station. Second objective is verifying and improving operational interfaces with the operator of the host satellite.

Since there will be a gap between the activation of the LCT on Alphasat and the first low flying customer, the development of the ground system is split in two parts, the first stage will enable DLR to support the test with the relay satellite and allow the project then to include lessons learned into the completion of the system to perform the operations with the target constellation of 6 terminals.

The first two customers will be the LEO satellites Sentinel-1A and Sentinel-2A of ESA (European Space Agency). DLR/GSOC will interface with different ESA entities at different stages of the program and exchange different products.

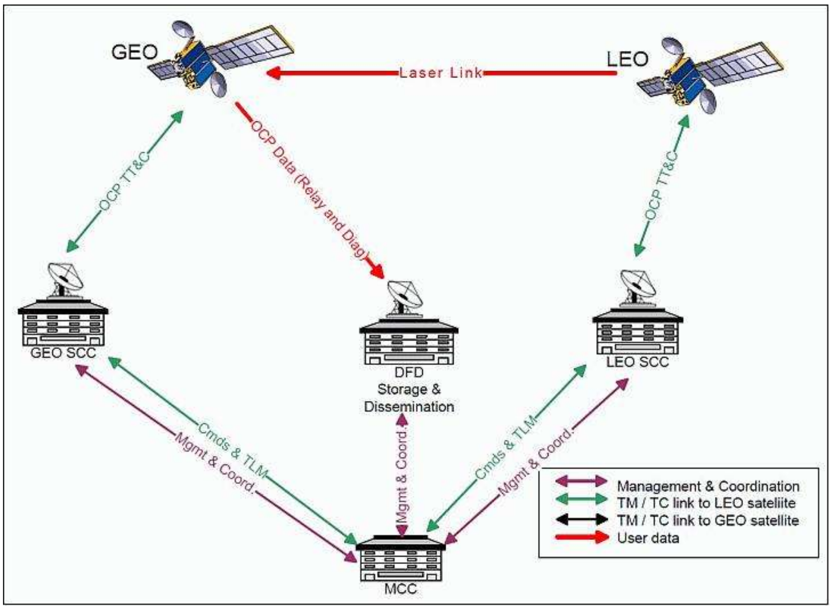

Figure 41: Schematic view of the TDP1 GEO relay system (image credit: DLR/GSOC)

Elements of the TDP1 system:

LEO (Low Earth Orbiting) satellite:

The LEO is typically an earth observation satellite carrying one or more instruments that generate user data that have to be transferred to ground. In the conventional approach the data is transmitted to the ground through ground stations, for example in X-band (not shown in Figure 41). In the case of a relay satellite, the LEO transfers the data to the GEO satellite (link in red). Consequently the LEO has to be equipped with a high-data rate LEO to GEO communication device. In order to be able to transfer large amounts of data, at least two technologies might be used:

1) Optical communication with a laser terminal, i.e. the LCT (Laser Communication Terminal)

2) RF (Radio-Frequency) communication in Ka-band.

For the sake of clarity, only one LEO is shown in Figure 41. In fact, various LEOs may use the relay satellite either in parallel, or one after the other, depending on the technical implementation.

LEO SCC (LEO Satellite Control Center):

The LEO SCC operates the LEO satellite. It is responsible for housekeeping and payload operations. Among these tasks is the correct pointing and activation of the LEO to GEO communication device. For a correct pointing of the communication device towards the GEO, the GEO orbit has to be known to the LEO SCC.

GEO Relay Satellite:

The GEO spacecraft receives the user data from the LEO satellite and relays it to the ground. For this purpose it needs a receiver, which is compatible with the terminal of the LEO. Therefore, the same technologies come into consideration, namely LCT or Ka-band. As for the LEO, these devices are usually steerable and have to be pointed towards the LEO, depending on the used technology.

To complete the relay function, the GEO spacecraft needs a high data rate terminal to send the data to the ground. The technology that can be used for this purpose, is not dependent on the LEO to GEO link. To receive a comparable data rate, the Ka-band is used. TDP1 has one dedicated receive station, but the space to ground beam for a GEO satellite may cover a very large portion of the Earth, which enables various ground stations spread over large distances to receive the data in parallel. This is planned for the EDRS system.

GEO SCC (GEO Satellite Control Center):

The GEO satellite control center operates the GEO satellite. It is responsible for housekeeping and payload operations. Among these tasks is the correct pointing and activation of the receiver. In order to correctly point the receiver to the direction of the LEO satellite, the LEO orbit has to be known to the GEO SCC.

DLR/DFD (German Remote Sensing Data Center):

DFD provides the ground station that receives and stores the data transmitted by TDP1's Ka-band antenna.

MCC (Mission Control Center):

The TDP1 MCC is the core element in the system. It interfaces with all other components and coordinates them. Its main purpose is to receive all the link requests from the different users and generate a link session timeline, taking all known constraints into account. In addition it monitors and controls all involved infrastructure. Depending on the request of the customer, the MCC can extend its service to include all preparations for a data transfer, including preparation of procedures and generation of associated command files.

LCT operations development at DLR/GSOC:

Operations of TerraSAR-X:

GSOC became involved in LCT operations for the first time with the program TerraSAR-X, which hosted the LCT (Laser Communication Terminal) as a secondary payload. A second LCT is flying onboard the US DOD satellite NFIRE (Near Field Infrared Experiment), which is operated by the company Orbital Sciences Corporation (Orbital). NFIRE was launched in April of 2007 with TerraSAR following in June of the same year. GSOC is the operator of the TerraSAR-X and also commands the LCT. The TerraSAR-X LCT is designed for two types of contacts, a satellite to ground link and ISLs (Intersatellite Links). As the objective in this case is test and evaluation of LCT operations, the responsibilities are divided between GSOC, as the satellite operator, and the LCT manufacturer, Tesat Spacecom. The first LCT tests on TerraSAR were SGLs (Space-to-Ground Links), performed with ground terminals located on DLR property in Oberpfaffenhofen near Munich and on the island of Tenerife. The first ISLs were exercised starting in January of 2007.

Essential to all LCT operations is the planning cycle which is an iterative process. Starting out with the different orbit information one party, in case of TerraSAR-NFIRE ISLs, Orbital, calculates the link options and makes a pre-selection with available links. GSOC then coordinates of the final link selection and publishes the deconflicted links to all parties. The two control centers for TerraSAR and NFIRE then prepare individually their respective LCT operations, with input from the instrument manufacturer Tesat (in form of command input files) and their flight dynamics departments, which are Chebychev coefficients for the LCT pointing. GSOC then produces the detailed SOE (Sequence of Events) and provides it to Tesat. After the links, GSOC and Orbital make a quick determination of the success of the operations and provide all the corresponding data to Tesat for evaluation. Results then flow into the input for the next links.

Occasionally other partners like the DLR/IKN (Institute of Communication and Navigation) request the opportunity to perform SGLs using their own optical ground stations. In that case, those partners provide their objectives to Tesat for them to generate the LCT configuration files and GSOC again publishes the SOE and performs the operations.

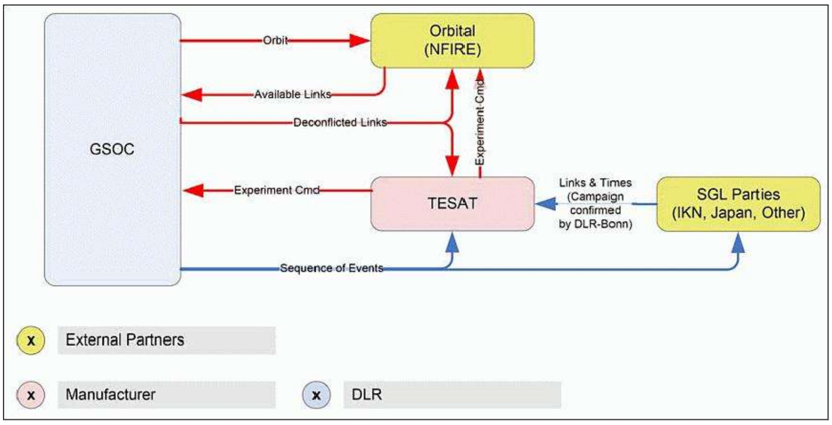

Figure 42: TerraSAR-X LCT operations concept (image credit: DLR/GSOC)

TDP1 System Design:

The next step in the evolution is the project TDP-1. TDP-1 is an experimental mission giving the proof of concept of a relay for Earth observation data from LEO spacecraft via a GEO satellite using laser as a transfer media. It is considered a precursor mission to the EDRS (European Data Relay System) project.

GSOC's objective in the program is to establish a control center for LCT relay operations providing end-to-end service of data transfer from a LEO spacecraft via a relay satellite to the final data user. That means in theory a handover of the data at the originating source, i.e. the LEO satellite and delivery to a dedicated ground station or end user. In practical terms GSOC will be capable to execute all data transfer functions, including the operations of all participating laser terminals and RF equipment.

The TDP-1 payload, hosted on the geostationary satellite Alphasat, consists of a laser communication terminal, mainly for the ISL to a LEO spacecraft, and a Ka-band payload for the data downlink from the GEO satellite. GSOC started the preparatory design for the TDP-1 project in late 2011. The laser terminal can also be pointed to an optical ground station, a functionality that will be used during the commissioning phase for calibration purposes. The launch of the geostationary relay satellite Alphasat was on July 27, 2013. Sentinel-1a as the first LEO customers followed on April 3, 2014.

The participating agencies in the TDP-1 project are the DLR (German Aerospace Center) as the contracting entity or customer, with its institutes GSOC and DFD, Inmarsat hosting the GEO payload, Tesat Spacecom as the LCT manufacturer, and the European Space Agency as the first LEO customers.

The concept of operations for GSOC is that GSOC collects the orbital information of all participating spacecraft and possibly the ground contact information of the LEO satellites. It then performs visibility calculations and publishes visibility reports for periods of one week and collects link requests. On a specific day, GSOC forwards the final link selection to the TDP coordination office (TECO) at Inmarsat and receives feedback the next morning. Then, GSOC prepares the command information for all participating laser terminals. The downlink from the Alphasat is received via Ka-band at DLR/DFD, and the data is distributed from there. GSOC receives a report about the success of the link and LCT diagnostic data for Tesat for evaluation of the LCT performance.

The LCT terminal onboard Alphasat is also capable of contacting optical ground stations. This feature will be used for testing and calibration during the commissioning phase, when no LEO satellite is available. The first ISLs are planned for the first quarter of 2014.

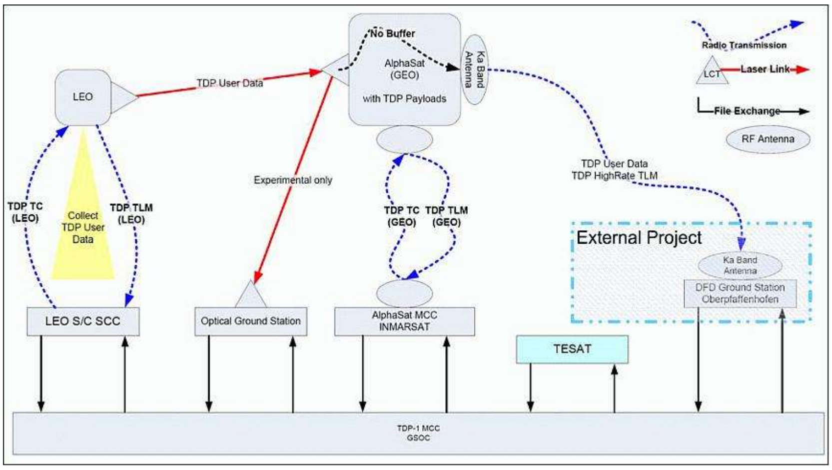

Figure 43: Overview of elements in the TDP1 project (image credit: DLR/GSOC)

The information being exchanged between the GSOC and the partners are:

• LEO SCCs to GSOC: Orbit information, link requests, possible constraints, TLM

• GSOC to LEO SCCs: Link possibilities, SOEs, LCT command inputs

• Inmarsat/TECO to GSOC: Orbit information, deconflicted links, TLM, command logs

• GSOC to Inmarsat/TECO: link list, SOE, command inputs, telemetry requests

• Tesat to GSOC: link requests, command inputs

• GSOC to Tesat: SOE, status reports, TLM, command logs.

Operations: The first activities for TDP1 after the launch of Alphasat were to perform selftests and use SGLs for calibration purposes. The selftests were executed while the LCT manufacturer was on site at the Inmarsat control center, thus without active participation of the SCC. During that time though, the complete data transfer chain went through the operational test phase. For the SGLs, GSOC became involved in the operations cycle. During that period the planning process was verified, including the checks implemented in the system and so some inconsistencies within procedures and databases between the individual parties (Tesat/DLR/Inmarsat) were discovered and corrected.

In March 2014, the preparations for the operational testing of the interfaces between the TDP1 MCC and ESA for the Sentinel-1 A support were in their final stages (Ref. 67).

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The information compiled and edited in this article was provided by Herbert J. Kramer from his documentation of: "Observation of the Earth and Its Environment: Survey of Missions and Sensors" (Springer Verlag) as well as many other sources after the publication of the 4th edition in 2002. - Comments and corrections to this article are always welcome for further updates (herb.kramer@gmx.net).

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