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Review

AstroSat – Configuration and Realization

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Abstract. AstroSat is India's first space-based observatory satellite dedicated to astronomy. It has the capability to perform multi-wavelength and simultaneous observations of cosmic bodies in a wide band of wavelengths. This paper briefly summarizes the challenges faced in the configuration of AstroSat spacecraft, accommodation and sizing of its critical subsystems, their realization and testing of payloads and the integrated satellite.

Keywords. Astronomy—AstroSat—spacecraft configuration—payloads—space environment—vibration—acoustic—cleanliness and contamination control.

1. Introduction

AstroSat mission (Koteswara Rao *et al.* 2009) is aimed to design, develop, fabricate and launch India's first dedicated astronomical observatory. The minimum useful life of the AstroSat mission is 5 years. The lift off mass of the satellite is 1513 kg. The satellite was launched by the Polar Satellite Launch Vehicle (PSLV-C30) on September 28, 2015 at 10:00 h IST. AstroSat attained a circular orbit of altitude 650 km and 6° inclination with respect to the equatorial plane. Deployed configuration of AstroSat is shown in Fig. 1.

AstroSat is meant to observe galactic and extragalactic cosmic sources. A complete understanding of these cosmic sources involve enhanced sensitivity, spectral and timing resolution studies. AstroSat observes in a wide range of wavelengths spanning from optical, ultraviolet, soft X-ray and hard X-ray regions of the electromagnetic spectrum by carrying on-board a complement of instruments sensitive over a wide spectral region covering visible (320–550 nm), ultraviolet (130–300 nm) and X-ray band (0.3–100 keV) enabling simultaneous multi-wavelength monitoring to study temporal and spectral variability. This multi-wavelength and simultaneous observational capability is the uniqueness of AstroSat.

2. Payloads on board AstroSat

There are four instruments sensitive in the X-ray band and one instrument with two telescopes covering the visible, near-UV and far-UV bands. Following are the five AstroSat payloads (Fig. 2, Singh *et al.* 2014):

(i) Large Area X-ray Proportional Counter (LAXPC) has three detectors covering 3–100 keV region. Each detector weighs 130 kg and has a dimension of 1193 mm length × 568 mm width × 690 mm height.
(ii) Cadmium-Zinc-Telluride Imager (CZTI) telescope sensitive in 10–100 keV, which weighs 49.5 kg and has an envelope of 530 mm length × 510 mm width × 813 mm height.
(iii) Soft X-ray Telescope (SXT) performs imaging and spectral studies in 0.3–8 keV region, weighs 52 kg and has an envelope of 382 × 580 × 2482 mm length.
(iv) Scanning Sky Monitor (SSM) for scanning the sky for unknown X-ray sources in 2.5–10 keV region, weighs 64.7 kg and has an envelope of 1200 mm length × 563 mm width × 543 height.
(v) Ultra Violet Imaging Telescope (UVIT) consists of twin telescopes. One telescope covers Far UV (FUV) band (130–180 nm) and the other in Near-UV (NUV) band (200–300 nm) and visible band (320–550 nm). The telescope weighs 201 kg and has an envelope of 877 mm diameter × 3100 mm length.

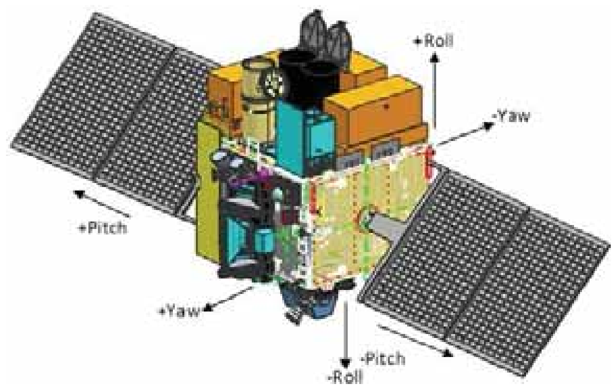


Figure 1. AstroSat spacecraft deployed configuration.

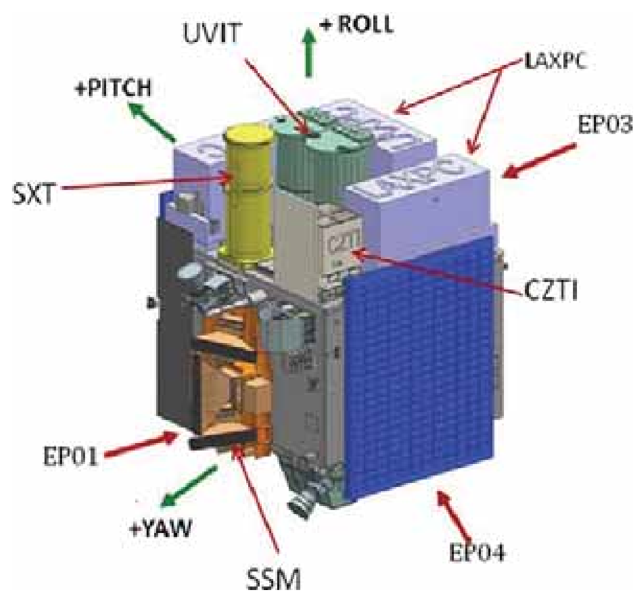


Figure 2. AstroSat spacecraft (stowed configuration).

3. Mission and science objectives

3.1 *The major AstroSat mission parameters*

The major AstroSat mission parameters are as follows:

Altitude: 650 km
Inclination: 6°
Orbit period: 97 min
Eclipse: 37 min (max)
Visibility: 5 to 12 min (for ground station at Bangalore)
Operational life: $\geq$ 5 years
Satellite lift off mass: 1513 kg
Power: 2100 W
Launch Vehicle: PSLV- C30
Data download rate: 105 Mbps in 2 chains

3.2 *Mission objectives*

(a) To provide an operational space-based multi-wavelength astronomical observatory with a minimum useful life of 5 years.
(b) To build a data reception station to receive scientific data from the spacecraft.
(c) To develop a data facility for formatting, archival, dissemination and utilization of the scientific data

The science objectives of AstroSat mission are:

(a) Multi-wavelength observations
  - AstroSat mission is designed for multi-wavelength studies of a wide variety of both galactic and extra-galactic sources.

(b) Broad band X-ray spectral measurements
  - Emission and absorption features with medium energy resolution capability in the 0.3–100 keV spectral band with 3 co-aligned X-ray instruments.
  - Study both non-thermal and thermal components.

(c) High resolution imaging of galactic and extra-galactic sources
(d) High time-resolution studies
  - Periodic and aperiodic X-ray variability in X-ray binaries.
  - Study of evolution of pulse and orbital periods.

(e) Detection of new transient X-ray sources

4. Spacecraft configuration

The overall spacecraft configuration accounts for the overall mission requirements, support payload operation and accommodate all subsystems required for the satellite mission. The satellite configuration consists of major subsystems like structure, mechanisms, thermal, propulsion, power, sensors, actuators, RF communication, data handling and payload data storage and onboard computers. The redundancy is built into the configuration either at the package level or at the card level for critical subsystems. Configuration also considers the sizing and accommodation of subsystems and payloads to meet their onboard functional requirements and also the integration and testing aspects of the satellite like field-of-view, and mounting of payloads with respect to the satellite axis, sizing or shaping of structure to accommodate payload envelope, and mechanical mounting to meet the structural requirements and onboard thermal aspects.

4.1 *Accommodation of payloads and co-alignment requirements*

Each of the five payloads had its own mounting requirements on the satellite. Four payloads (UVIT, LAXPC, SXT and CZTI) required co-alignment. Accordingly, three payloads viz, LAXPC, SXT and CZTI are mounted the top deck of the satellite while UVIT payload is fastened to the satellite central cylinder and all are co-aligned to the satellite Roll axis thus enabling all the four payloads to point to the same source for simultaneous and multi-wavelength observation. The fifth payload, SSM, which is to be rotated about its axis to scan the sky, is mounted on the anti-Sun side of the satellite and is orthogonal to the other four payloads. The rotation axis and view axis of one of the SSMs (SSM3) is aligned with Yaw axis of the satellite. The accommodation of payloads, their processing electronics and satellite main frame subsystems are shown in the exploded view of AstroSat (Fig. 3). Fully integrated flight hardware of AstroSat is shown in Fig. 4.

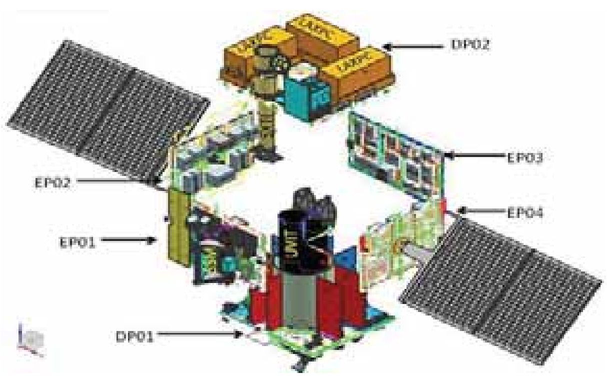


Figure 3. Exploded view of AstroSat configuration.

Figure 4. Fully integrated AstroSat spacecraft.

Table 1. FoV specifications and clearance achieved.

Subsystem	FoV specifications achieved
UVIT	+/−5°
SXT	5° half cone
SSM	Along long axis: +/−52° Along short axis SSM1 and SSM2: +/−14° SSM3: +/−12°
LAXPC	15° half cone
CZTI	17° half cone
Star Sensor Sn-31	+/−50°
Star Sensor Sn-32	+/−50°
SPS-22	2Pi steridian
PAA-10	2Pi steridian
PAA-20	2Pi steridian
SANT-10	100° half cone
SANT-20	100° half cone
4PI Sun sensor	4Pi steridian

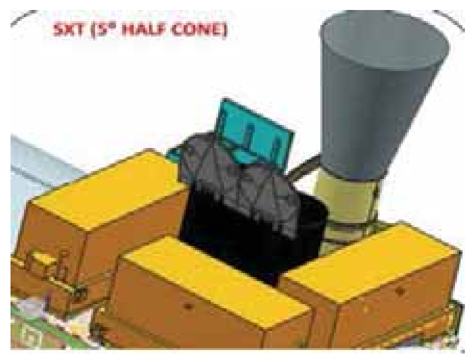


Figure 5. FoV of SXT payload.

4.2 *Field-of-view, bright object avoidance and scatter effects*

Payloads and sensors have their own fields-of-view (FoV), bright object avoidance requirements and also minimum impact of scatter. The antennae also have the requirements of FoV clearance. The details of the FoV clearances achieved are given in Table 1.

The FoV aspects of few payloads and star sensors are shown in Figures 5–10.

Sun avoidance requirements of payloads are met by tilting the satellite away from the Sun vector by 45° as part of mission management.

The payload cover of UVIT, black coating of the exposed surfaces of payload (UVIT and SSM payloads) or the material used in the payload construction (CFRP material in SXT payload) and baffles of the respective payloads help in minimizing the scatter effects.

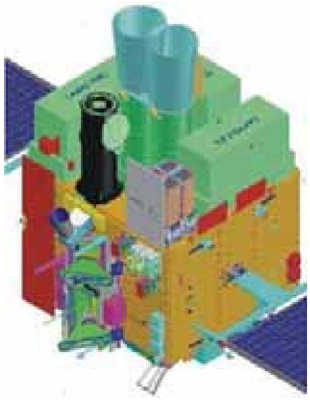


Figure 6. FoV of UVIT payload.

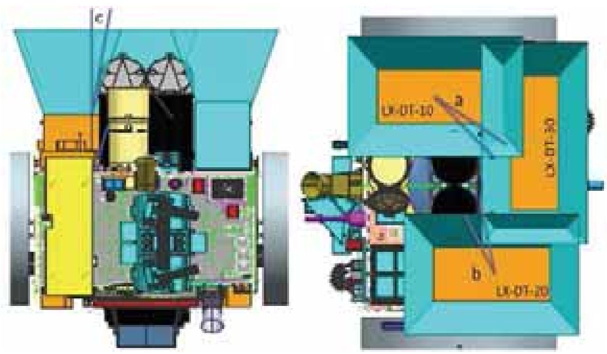


Figure 7. FoV of LAXPC payload detectors.

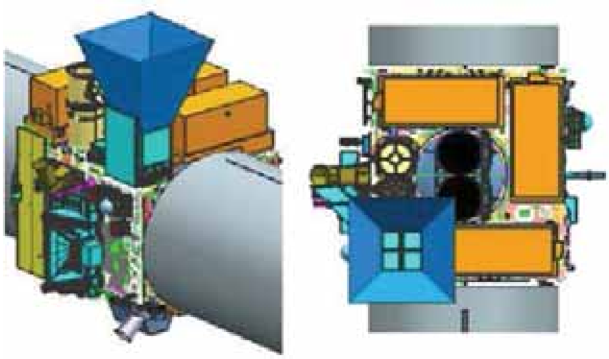


Figure 8. FoV of CZTI payload detector.

Figure 9. FoV of SSM payload detectors.

4.3 *Subsystems sizing and configuration*

4.3.1 *Structure subsystem.* Satellite structure is cuboid in shape with a central CFRP cylinder, shear panels, four vertical equipment decks and two horizontal decks. The CAD model of AstroSat structure (exploded view) is shown in Fig. 11.

All the decks are of aluminum honeycomb sandwich construction to meet the payload and subsystems mounting requirements. The decks are shaped, sized and reinforced with either metallic embedment (for 3 units of LAXPC) or with doublers to meet payloads/subsystems mounting requirements. The horizontal (top and bottom) decks have 'U' shaped cutouts to meet accommodation and integration requirements of the SXT payload with satellite.

The structure is configured with shear panels (8 numbers) to provide the required stiffness and strength to the decks and the satellite as a whole. The positions of shear panels also addresses the mounting requirements of heavy payloads like LAXPC, SXT and SSM on the decks. Shear panels are of composite construction in nature and are permanently attached to the central CFRP cylinder. The central CFRP cylinder has metallic interface ring at its bottom end to interface with the launch vehicle. The cylinder supports top and bottom decks. The bottom deck is located at around 300 mm away from the interface ring to take care of the protruding elements of SXT payload and also to accommodate the reaction wheels below the bottom deck. The realized structure hardware is shown in Fig. 12.

4.3.2 *Mechanisms subsystem.* AstroSat is configured with deployable mechanisms for solar arrays and for payloads (SSM, UVIT and SXT). There are two solar arrays each having two solar panels. Each solar panel is having a dimension of 1400 mm length $\times$ 1800 mm width $\times$ 20 mm thickness.

4.3.2.1 *Solar Array Mechanism.* Each array has an independent deployment mechanism. They have two mechanisms viz. 'hold' (stowed configuration during launch) and 'release' (deploy after satellite separation). The natural frequency of the deployed array is more than 0.25 Hz. The solar array deployed view is shown in Fig. 13.

4.3.2.2 *Mechanisms for payloads.* SSM payload is configured with three mechanisms. Hold (stowed during launch), release (after satellite separation from the launch vehicle—the payload pops up by 2 mm from its mounting plane) and rotation mechanism. The natural frequency after deployment is estimated to be

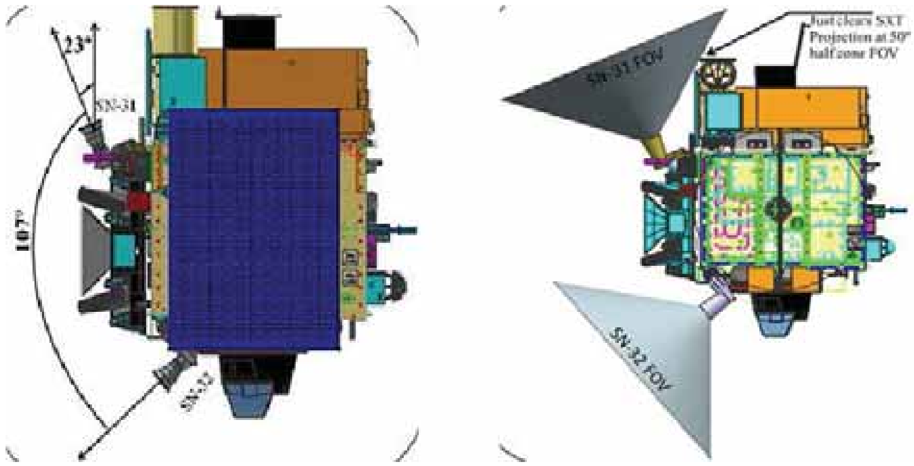


Figure 10. Mounting position and FoV of star sensors.

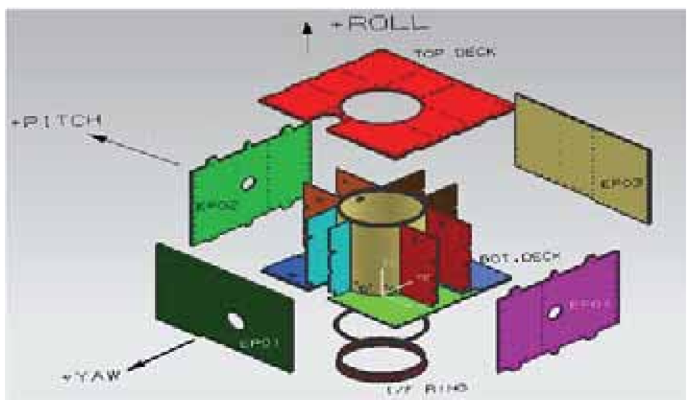


Figure 11. Exploded view of the AstroSat structure.

Figure 12. AstroSat structure hardware.

Figure 13. Solar array deployment configuration.

5.7 Hz. The stepper motor helps the payload to rotate by +/−175, parallel to its mounting plane. The operating rotation speed is 10° in 12.5 s in step and stare mode and the angular positional accuracy being a maximum of 1 arc min. The flight integrated SSM payload hardware held with a fixture is shown in Figure 14. The location of hold and release mechanism elements of the payload is shown in Figure 15.

The SXT payload cover has two mechanisms: hold (stowed during launch) and release (deployed after satellite separation in the orbit). Paraffin actuator is used in hold and release mechanism while tape spring is used in the deployment mechanism. The mechanism is designed to deploy the door by 256° from its hold down

Figure 14. SSM payload flight model.

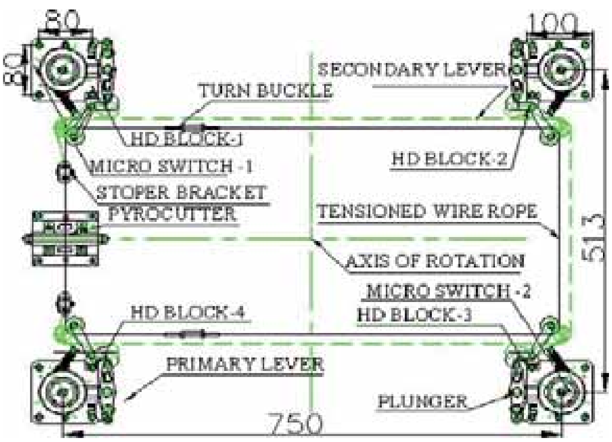


Figure 15. Hold and release mechanism elements.

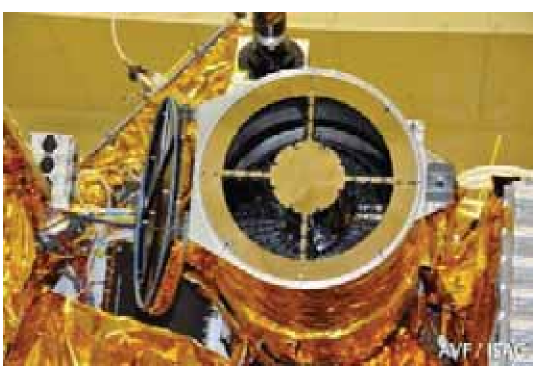


Figure 16. SXT flight model with deployed payload cover.

condition to avoid FoV blockage of nearby mounted star sensor. The natural frequency of deployed cover is more than 2 Hz. The deployed view of SXT payload cover is shown in Fig. 16.

The UVIT payload has two identical but independent deployable doors. Each door has hold and release mechanisms similar to that of the SXT payload. The mechanism is designed to deploy the doors by 95° from its hold down condition to clear its own FoV. These doors also serve as sun shade for the payload. The deployed view of the UVIT payload cover is shown in Fig. 17.

Figure 17. UVIT payload flight hardware with deployed payload covers.

4.3.3 *Thermal subsystem.* AstroSat is a 3-axis stabilized inertial pointed satellite in a near equatorial orbit. The thermal design and control is driven by the external heat inputs, internal thermal dissipation due to subsystems, payloads, and the stringent thermal environment requirements of payloads and subsystems. Thermal gradient along the telescope lengths of SXT and UVIT payloads also needs to be controlled. These conditions make the thermal design and control more complex.

The prime factors affecting external thermal load variation in AstroSat are as follows:

- The Sun always lies in the negative Yaw and Roll plane.
- + Yaw panel is always on the anti-Sun side.
- The Sun vector should always make more than 45° with the roll axis which is the pointing direction of 4 of the co-aligned payloads.
- The Sun aspect angle varies with seasons and regression of nodes.
- Change of solar constant with seasons.
- Change in eclipse duration with aspect angle.
- Change in orientation of AstroSat to look at different sources.
- Degradation of thermal properties with time.

The thermal system is designed to protect the satellite subsystems and payload systems against the harsh

Figure 18. Flight LAXPC payload model with thermal control elements.

space thermal environment. This is achieved by thermal isolation and the use of space qualified thermal control elements such as Optical Solar Reflectors (OSR), Multi Layer Insulation (MLI), active thermal control heaters, quartz wool blanket, sink plates and ammonia heat pipes embedded in the satellite decks. All these help to maintain the complete satellite within its operating temperature limits of 0°C to 40°C.

Also, appropriate thermal control systems are designed and developed for individual payloads to meet their required thermal working environment (temperature limits for detectors and thermal gradients of the payload structure) with the help of suitable isolation, active control heaters, heat pipes (both ammonia and ethane) and appropriately-sized radiator panels.

The LAXPC payload detector with front end electronics, dissipates a thermal heat of 65 W, and needs to be maintained between 10°C and 35°C. The thermal control design is achieved by thermally isolating the payload detector from the satellite, covering the top window (which is exposed to deep space by 0.3 mil thick aluminized kapton, putting 15 layers of MLI on the side walls of the detector with radiative OSR windows at selected zones on the collimator. Thermal control elements implemented on LAXPC is shown in Fig. 18.

The CZTI payload is configured with 64 numbers of CZT detector modules, mounted on detector board. The detector board needs to be maintained between temperature limits of 0 °C and 20 °C (design limits). This is achieved by using three L-shaped ammonia heat pipes to radiate out to space a total thermal dissipation of 64 W from the payload by specially designed radiator panel, as shown in Fig. 19(a), (b).

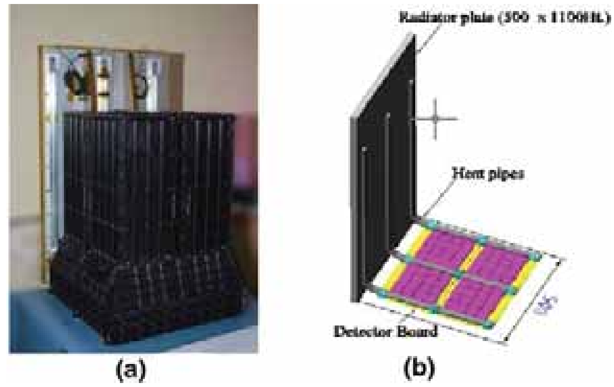


Figure 19. **(a)** CZTI payload assembly, and **(b)** heat pipe layout (schematic).

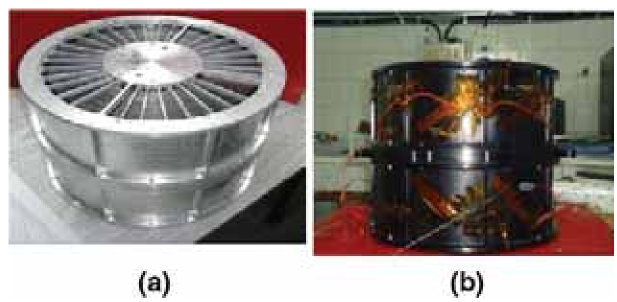


Figure 20. **(a)** Bare optics module of SXT and **(b)** SXT optics module with thermal elements.

The SXT payload has two critical sub-assemblies, the optics module which is an assembly of a series of gold-coated aluminum foils and the Focal Plane Camera Assembly (FPCA) which consists of an X-ray CCD mounted with a Thermal Electric Cooler (TEC) and other elements like detector electronics. The operating temperature limits of 15°C to 25°C (with necessary qualification margins) for X-ray optics module is achieved by control heaters on the optics housing and by radiative heating by heaters mounted on the thermal baffle (mounted inside the SXT payload structure just above the optics module) and by covering the optics module by an MLI blanket. The optics module of the SXT payload is shown in Fig. 20(a), (b).

The FPCA containing TEC dissipates around 10 W of thermal heat through a cold finger. The cold finger is required to be maintained at −40°C and the TEC in turn will help to maintain the detectors at −80°C. Maintaining TEC temperature at −40°C through cold finger is achieved with the use of ethane heat pipe thermally connecting one end to the cold finger and rest of the length fastened to suitably sized radiator panel system. The thermal assembly of cold finger, heat pipe and radiator panel is shown in Fig. 21.

Figure 21. Focal plane camera assembly, heat pipe and radiator assembly.

The UVIT payload has back focal plane assembly below the primary mirror assembly containing three detectors (with detector electronics). This is to be maintained between 0°C and 20°C. Three high voltage units and three filter wheel drive units are to be maintained between 0°C and 40°C. The telescopic tube between the primary and the secondary mirror needs to be maintained at 20 +/−3°C The total thermal dissipation in the back focal plane volume is 15 W that needs to be accounted for along with external thermal inputs depending upon the satellite orientation during observation. The CAD model views of UVIT payload assembly (mounted with titanium adaptor) and the back focal plane assembly are shown in Fig. 22.

The thermal control of the payload is achieved by combination of thermal isolation, use of active heaters and radiating zones on payload body. Thermal isolation of payload from the satellite is achieved by a titanium material adaptor which mechanically interfaces payload to satellite central cylinder. The use of the 15 layer MLI all around UVIT tube, isolation of back focal plane assembly contamination cover from telescope tubes, auto heaters on aluminum plates (below the primary mirror), OSR windows on certain zones of contamination cover's external surface and high emittance surfaces are other measures implemented in thermal design. A large number of heaters on the telescope tubes control the thermal gradient.

Figure 23. SSM payload assembly hardware.

The SSM payload has three independent gas detector counters mounted on a CFRP platform along with its front-end electronics packages. The detectors need to be maintained between the temperature limits of 5°C and 35°C. The integrated SSM payload hardware is shown in Fig. 23.

The required thermal design and control is achieved by covering the detector housing top (which is exposed to deep space) by 0.3 mil thick aluminized kapton and

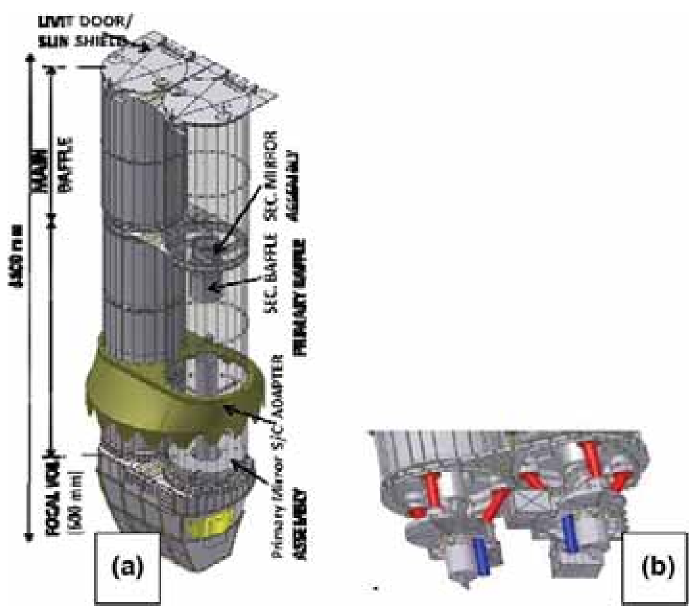


Figure 22. **(a)** UVIT payload assembly with TI mounting adaptor and **(b)** back focal plane assembly.

covering the entire payload including CFRP platform with 15 layer MLI along with OSR radiating window (on amplifier and front-end electronics packages) and active control heaters (on detector housings, logic boxes and CSPA packages) on the packages on the rotating platform.

The quantum of thermal control elements used (245 thermistors, 62 fine temperature sensors and 791 heater elements, optical solar reflectors, MLI, heat sink plates and heat pipes radiator plate assembly) in spacecraft speaks of the complexity involved in thermal control design.

4.3.4 *Propulsion subsystem.* The propulsion system of AstroSat is minimally configured for emergencies with monomethyl hydrazine fuel with nitrogen as pressurant medium and operating in blow down mode. The hardware elements consist of 8 numbers of 11N hydrazine catalytic thrusters, two fuel tanks, each of 30L internal volume. The quantity of fuel loaded is 42 kg and 0.5 kg of nitrogen. All the propulsion elements are accommodated on the satellite bottom deck. Nominally, the momemtum desaturation of reaction wheels is being performed periodically using magnetic torquers. As part of fuel budget estimation a preliminary study of momentum dumping showed that for AstroSat inertial pointing orientations, only about 60% of the time the momemtum dumping is successful with 60 Am^2 capacity torquers. The unserviceable orientations are for a set of latitude bands for a season and vary with changing seasons. A fuel budget of 17.3 kg is estimated and accounted (for 5 year life time) under momentum dumping to service satellite orientations. However, all the maneuvers and control of satellite is planned to be done using wheels and gyros to minimize contamination.

Plume studies and thruster exhaust gas chemical composition analysis are also performed as part of contamination assessment.

4.3.5 *Power subsystem.* AstroSat power system consists of two solar arrays with two panels each, two batteries of 36 AHr capacity, and power electronics for control and distribution to various subsystems. Solar panels are populated with ATJ cells to generate 2100 W power. During the full orbit, except for the eclipse period, the solar panels are oriented normal to the Sun in order to generate maximum power. The battery consists of 240 Li-ion cells connected in the configuration of 10 in series and 24 cells in parallel to store, and provide the required capacity and operating voltage to support during eclipse and payload operation when solar power may not be adequate. Power electronics helps to control and distribute the power to various subsystems. The system is designed for a mission life of 5 years. The power system is a battery tied dual bus system with two raw buses viz. Bus-A and Bus-B each is 30 V–42 V range.

The realized power package electronics packages are as shown in Figures 24 and 25.

4.3.6 *On-board computer, sensors and actuators.* AstroSat is configured with two on-Board Computers (OBC) to serve as main and redundant system. It is an ASIC based BUS Management Unit each with 14 cards assembly. It integrates various functions such as sensor electronics, command actuators to achieve the attitude and orbit control requirements, thermal management, housekeeping, etc. It also implements the MIL STD 1553B protocol for interfacing with other sub-systems of the spacecraft. Spacecraft autonomy is realized in OBC as it is a centralized information processing system.

AstroSat is configured with 4 solar panel Sun sensor which has an FoV of $+/-45°$, two star sensors (Mk-I) having an attitude accuracy of 40 arc sec along bore axis and 10 arc sec in cross axis, four 4Pi Sun sensors with an accuracy of $+/- 5°$, 3 digitally tuned Gyros housed in a single package, two tri-axial magnetometers with accuracy of $+/-500$ gamma for attitude, orbit and maneuver management of the satellite.

Actuators for attitude and orbit control incorporate four reaction wheels (10 NMs), 8×11 N thrusters and 3 magnetic torquers of capacity 60 Am^2. The realized on-board computer hardware is shown in Fig. 26.

The AstroSat is a three-axis stabilized satellite and inertial pointed to a target for observation. The orientation maneuvers and attitude control is done by reaction wheels with inputs from the gyros and star sensors. Magnetic torquers are used for momentum dumping. The slew operations, targeting and pointing for observation is managed by a Bus Management Unit. During slew and pointing the typical constraints considered are the solar avoidance $\geq 65°$, Earth limb avoidance $\geq 12°$ and RAM avoidance angle $\geq 12°$ to the view axis of the instruments. The pointing accuracy is 0.05 deg (3 sigma) in each axis and attitude drift rate is 3×10^{-4} deg/s. The control system for AstroSat is equipped with algorithms related to bright object/Sun avoidance, safe mode, SSM disturbance settling, data acquisition and data management.

4.3.7 *Data handling and storage subsystem.* The payload Data Handling System consists of a Base band Data Handling (BDH) system and a Solid State Recorder (SSR). The amount of data produced by payloads is

Figure 24. Core power packages of power subsystem.

Figure 25. Distribution and DC–DC convertor packages of power subsystem.

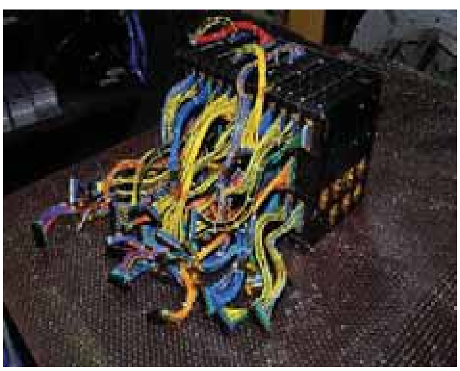


Figure 26. On-board computer of AstroSat.

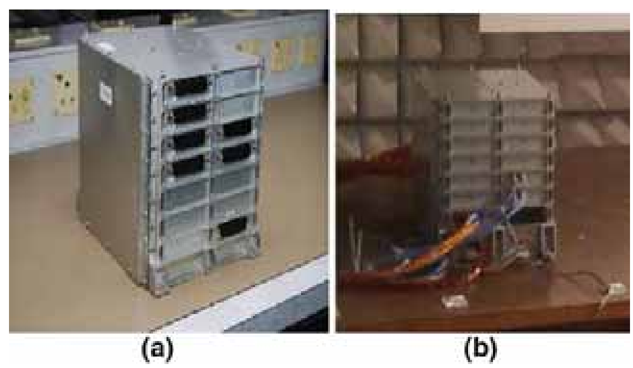


Figure 27. Data handling and storage subsystem flight hardware. **(a)** BDH package and **(b)** SSR package.

not constant and it depends on which part of the sky the payload is observing at and its mode of operation. Since all payloads are ON continuously, BDH and SSR has to be 'ON' continuously. Data transmission is only during visibility of spacecraft over the Indian region. Data has to be recorded into SSR and played back during ground station visibility. There is no real time transmission of data. The SSR has a capacity of storing 200 Gb data. The data generated in four orbits is 144 Gb. The realized flight hardware of data handling and storage is shown in Fig. 27(a), (b).

4.3.8 *RF communication system*. The Radio Frequency (RF) communication systems for AstroSat mission consists of Telemetry and TeleCommand (TTC) transponder systems in S-band, data transmission systems in X-band and Satellite Positioning System (SPS). The TTC system comprises of two chains of Phase-Locked Loop (PLL) coherent TTC transponders, a near Omni coverage antenna system for uplink and downlink chains and corresponding feed networks. The data is transmitted by two X-band carriers, once in all the visible orbits, at a rate of 105 Mbps each.

The X-band data transmission system comprises of four QPSK-modulated data transmitters and two electronically steerable Phased Array Antenna (PAA) systems. The phased array antennae are controlled by a common beam steering electronics. Spacecraft orientation is inertially fixed and hence its orientation with respect to earth and ground station changes

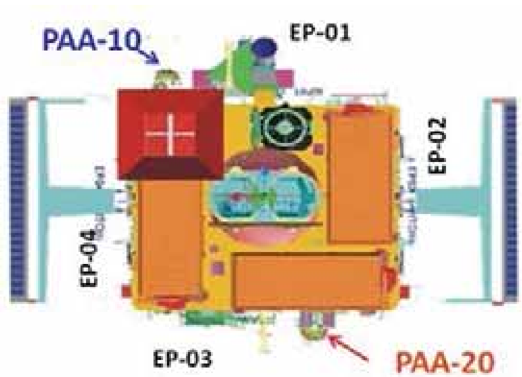


Figure 28. AstroSat top view showing accommodation of two-phased array antennae.

Figure 29. Phased array antenna (X-band antenna).

continuously. In order to satisfy the requirement of data download, two Phased Array Antennae (PAA-10 and PAA-20) are mounted on opposite side panels. The mounting location of PAA-10 and PAA-20 is shown in Fig. 28.

The Satellite Positioning System provides position vector information and also the GPS time interface to LAXPC payload. This timing signal is of prime significance in order to gather precise data of cosmic events. In certain inertial pointing directions, analysis suggests that with one SPS antenna (coverage of 170°) there could be an interruption of 1200 s in the timing signal. Hence two SPS antennae are mounted to provide coverage of 340° ensuring a minimum of 6 satellites all the time.

The RF communication realized packages are as shown in Figures 29–31.

5. Cleanliness and contamination control

Payloads like UVIT and SXT make use of highly sophisticated optics and electro-optical sensors which are very sensitive to contamination. UVIT specially demands great care to avoid molecular contamination of the optical surfaces during any stage of fabrication/testing/assembly and transport, etc.

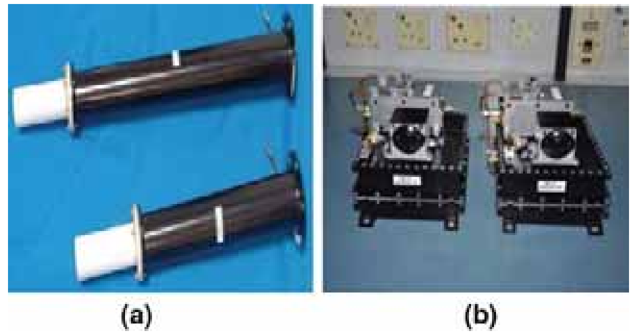


Figure 30. S-band TTC antenna system.

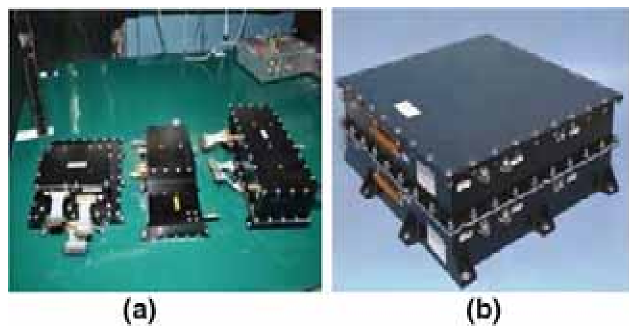


Figure 31. **(a)** X-band and S-band transmitter. **(b)** SPS package.

The contamination of an optical surface can be either due to deposition of the particles or due to deposition of the molecules. Air cleanliness levels of $<10{,}000/m^3$ and particle fall out of <50 mm^2/m^2/day was fixed for the clean room (for satellite integration) and in environmental test laboratories (for payload and AstroSat test activities), where the optical surfaces are not directly exposed to open environment. However, 100 class clean room was used for the payload assembly and test activities where the optical surfaces were exposed.

The prevention of molecular contamination demands a super clean spacecraft environment. This is addressed right from the design stage with selection of materials having very low out-gassing properties. All materials and processes used in any part of the spacecraft are subjected to a screening process, and based on contamination clearance the material or process is added into the approved Declared Material List (DML)/Declared Process List (DPL). The molecular contamination levels is based on reflectance and transmittance change which should be $<5\%$ in the 130–180 nm range.

Each of the hardware surfaces were visually inspected with UV light to assess the particulate contamination. All sub-system or components are cleaned with isopropyl alcohol, baked in vacuum at a high temperature for a long period (typically 96 h) and stored in dry

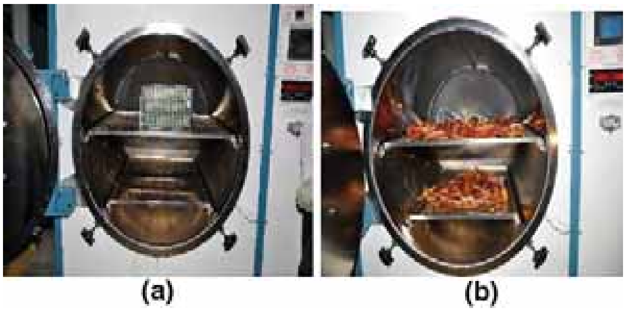


Figure 32. **(a)** Subsystem package baking, **(b)** harness baking.

nitrogen-filled bags, before getting integrated to the spacecraft. Aluminum witness mirrors and MgF_2 windows are used as witness samples for measuring possible contamination/degassing due to the material. Polymeric materials with low out-gassing properties only are used to the maximum possible extent. Marginal deviations from screening levels of less than 1.0% Recovered Mass Loss (RML) and less than 0.1% Collected Volatile Condensable Material (CVCM) were permitted only in the absence of functionally suitable alternative.

During vacuum baking of the hardware, visual inspection was carried out before as well as after baking. After initial baking of the hardware at the maximum permissible temperature, optical witness surface (MgF_2/Al/Zerodur mirrors) are introduced and baking is continued. Post baking, the measurement and analysis of optical witness surface data (change in reflectance and transmission) was performed and analysed for the contamination; the hardware was certified for integration based on assessment. The baking test set up is shown in Fig. 32(a), (b).

During thermovac testing, cleanliness was monitored using Temperature controlled Quartz Crystal Microbalance (TQCM), Resdiual Gas Analyzer (RGA) in addition to OWS and MgF_2 windows. Subsequently, MgF_2 window measurements were used to monitor molecular contamination levels during vibration, acoustic tests, evaluation of the transport container, during transportation and as well as at launch site facilities.

Such stringent contamination control criteria also demands special control practices throughout development, assembly, handling, storage, testing, packaging and transportation of the spacecraft. Severe constraints are also imposed on usage of permissible adhesives, epoxies, conformal coating and sealants. Nitrogen purging and venting also plays a key role for sensitive instruments against contamination. The use of protective covers and caps, ESD compatible latex gloves, clean room wipes and swabs are also an important necessity. Training sessions were conducted to personnel involved in flight hardware handling. Contamination control protocol such as clean room practices, entry and exit methods, baked hardware packaging and handling procedures, personal hygiene, area monitoring (hardware receiving area, moving in-between areas) and project janitor service protocols were introduced and implemented.

Such stringent contamination control exercise was possible by systematic implementation of protocols and guidelines.

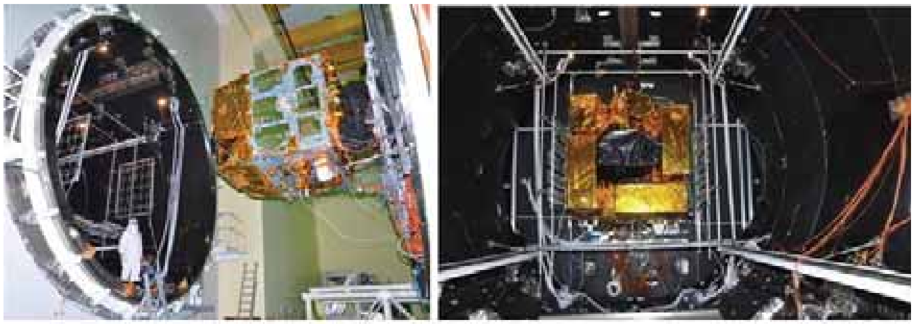
6. Interface and environmental tests

As the payloads were developed for the first time, the interface tests between each of the payload and the satellite subsystems like OBC, data handling and storage were performed, initially with subsystem simulators and later with actual hardware. End to end chain test with BDH, SSR, RF chain was also performed. As part of space environment qualification program, all subsystems and payloads underwent thermovacuum and vibration tests, at unit level, to establish design margins and also to unearth the manufacturing, assembly and workmanship defects. Payload-specific test fixtures were configured, designed and realized to perform vibration tests on the payloads. Infra Red (IR) cage set up were configured and realized for performing thermovacuum tests on the integrated payloads of SXT and UVIT to achieve the required temperature limits levels at different zones of payload. The functional performance of individual subsystems and payloads were assessed and verified to clear them for satellite integration.

Environmental tests like thermovacuum and dynamic (vibration and acoustic) tests were also performed on the integrated satellite to simulate the space environment and launch phase environment.

6.1 *Thermovacuum test on AstroSat*

A detailed thermal analysis was performed for the thermovacuum test set up configuration. A suitable IR cage (with IR lamps fitted) was configured around the satellite inside the chamber for heating of the satellite to ensure the payload sub-assemblies/subsystems attain the specified temperature limits during both cold and hot cycles. Special local cooling arrangement was also designed and realized to cool the back focal plane assembly of UVIT payload to control the detector temperatures during the tests. Arrangements were also made to measure the contamination level inside the chamber during these tests. The loading of AstroSat



(a) (b)

Figure 33. **(a)** Satellite getting loaded inside the TVac chamber, and **(b)** satellite the inside TVac chamber.

(a) (b) (c)

Figure 34. Vibration test **(a)** along lateral axis, **(b)** along longitudinal axis and **(c)** acoustic test on AstroSat.

inside the thermovacuum chamber and the satellite inside the chamber is shown in Fig. 33(a), (b).

6.2 *Vibration and acoustic tests on AstroSat*

Acceleration data obtained from the Structural Coupled Load Analysis (between AstroSat and Launch Vehicle) was used judiciously during the vibration tests on the integrated satellite by limiting the payload/subsystem acceleration responses to avoid overstressing of the critical sub-assemblies of the payloads and other satellite subsystems. Vibration and acoustic test setup for the integrated satellite is shown in Fig. 34(a)–(c).

7. Conclusions

Payloads on the AstroSat are very complex in nature. Some of them have better performance than the similar instruments on contemporary missions. The configuration of satellite by accommodation of these payloads with required FoV clearances has been met successfully. The subsystems have been suitably sized and designed to meet AstroSat requirements. The contamination control and monitoring process demanded different set of practices and protocols for the first time. Lastly, testing aspects were given a lot of attention whether it may be interface tests or environment tests, to ensure the quality of the product.

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