RISAT-1 spacecraft configuration: architecture, technology and performance

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RISAT-1 is the first indigenous active Radar Imaging Satellite launched by Polar Satellite Launch Vehicle (PSLV) in April 2012 from Sriharikota. It carries C-band Synthetic Aperture Radar (SAR) payload which can operate at various values of resolution and swath for various applications. RISAT-1 is the heaviest and high-power satellite with many new technologies to support the SAR payload and the associated elements. RISAT-1 operates at polar sun-synchronous orbit of 536 km altitude with the inclination of 97.554° and it is designed for 5 years lifetime. Performance of the spacecraft system and the SAR payload is satisfactory. This article outlines the architecture, design and on-orbit performance of RISAT-1.

Keywords: Architecture and design, radar imaging satellite, synthetic aperture radar payload.

Introduction

THE space-based remote sensing programme is applications-driven and covers observations on land, ocean and atmosphere. To serve these applications effectively, satellites need to fly various types of sensors which may operate in optical or microwave region of the electromagnetic spectrum. So far ISRO has operated satellites using both regions. While Indian Remote Sensing Satellite (IRS) series of satellites were mainly based on electro-optical sensors, there are other sensors like Multi-frequency Scanning Microwave Radiometer (MSMR), scatterometer and X-band Synthetic Aperture Radar (SAR) on OCEANSAT-1, OCEANSAT-2 and RISAT-2 respectively. Sensors operating in microwave region of electromagnetic spectrum have the capability to provide data during the day, night and all weather conditions. SAR technology provides data on structural information to geologists for mineral exploration, oil spill boundaries on water to environmentalists, state of the sea and ice hazard maps to navigators and reconnaissance data to strategic applications. SAR data is well suited for the quantitative observation of critical national and global resources such as tropical forests and will be a primary source of information for resource-monitoring and analysis.

The SAR programme began with C-band SAR for airborne applications and the user community is provided with imagery from airborne SAR and C-band imagery from RADARSAT-1/RADARSAT-2. The attributes of SAR imagery depend upon the sensor parameters such as frequency, polarization, look angle and the attributes of objects such as surface roughness, moisture content, orientation, dielectric constant, etc. Thus C-band was chosen for RISAT-1 to cater to a wide variety of applications.

The mission elements of RISAT-1 are:

- Space segment comprising three-axis stabilized satellite, flying SAR payload and mainframe systems.
- Data reception, recording, processing and dissemination facilities having the required hardware and software components on ground.
- Spacecraft control centre for tracking, commanding and receiving telemetry data for satellite health monitoring and analysis, orbit maintenance and payload programming functions.
- Development of user-friendly data products and data archival.

Orbit choice for RISAT-1

The main guiding parameter for choosing the orbit for RISAT-1 is achieving global coverage in a systematic way for a given swath. Other considerations such as the presence of atomic oxygen and atmospheric drag have also been kept in view.

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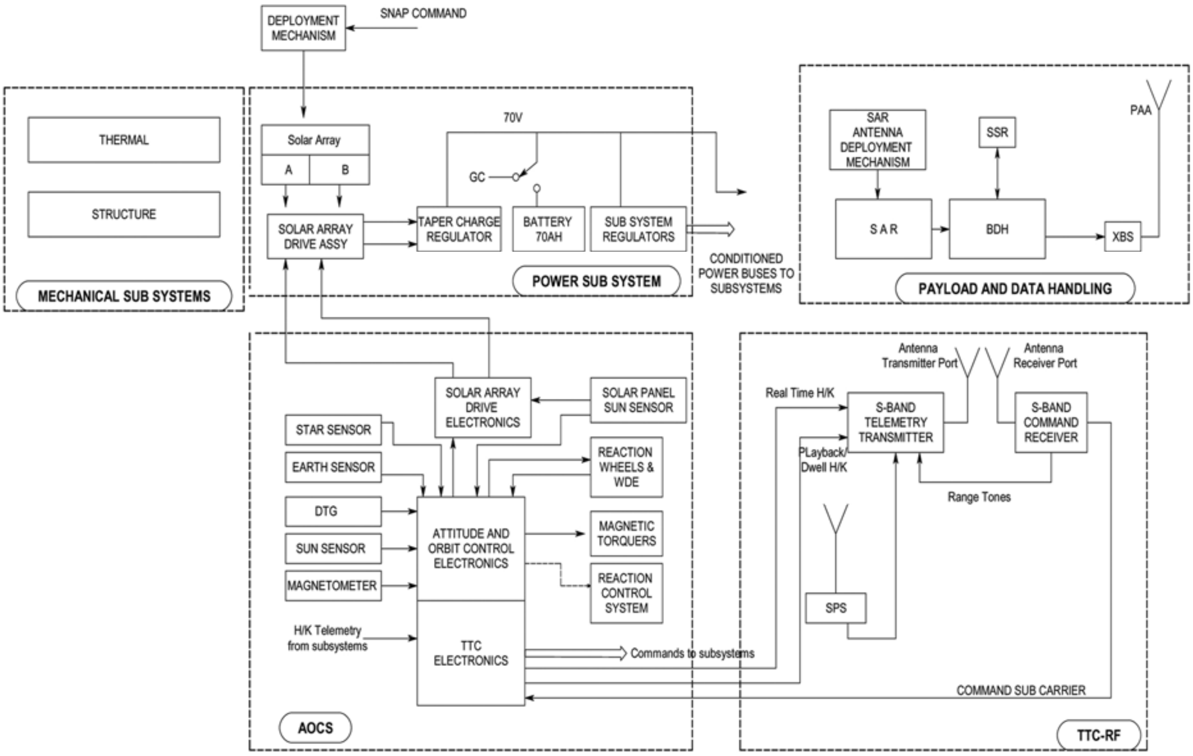

Figure 1. Block diagram of RISAT-1 spacecraft.

A polar sun-synchronous orbit at 536.38 km altitude and inclination of 97.554° with repetivity cycle of 377 orbits in 25 days is chosen. Global coverage is achieved twice in the repetivity cycle, once by a set of descending passes and next by a set of ascending passes, as SAR is a microwave payload with no illumination constraints.

RISAT-1 configuration and architecture

RISAT-1 is a high power, heavy-weight active microwave satellite. It is a 3-axis stabilized satellite operating in sun-synchronous 6 a.m.–6 p.m. orbit of 536 km. It carries the SAR payload supported by other mainframe elements. It can take images with ± 36° roll bias on orbit. The architecture is similar to that of earlier missions such that it supports the synthetic aperture microwave payload, electrically and mechanically. RISAT-1 adapted a technology for the mainframe system in order to meet its specification and requirements. The basic block diagram of RISAT-1 is given in Figure 1. It carries many new elements (with new designs) like power, battery, X-band modulator, phased array antenna (PAA), on-board computer, reaction wheels, solar array drive electronics and assembly, payload data handling system, structure and SAR antenna deployment mechanism. Single-point failure and redundancy for the subsystems have been taken care in the configuration.

The structure is built around a central cylinder with equipment decks for accommodation of subsystems. It has a unique structure carrying elements of bus system and payload system which is different from earlier remote sensing missions. The spacecraft bus subsystems provide basic housekeeping functions like orbit correction, attitude determination, thermal control, electrical power generation and distribution, ground communications, SAR image data handling and storage and data transmission to the ground. The bus module contains all the necessary systems to operate and maintain the spacecraft in orbit and support the SAR payload. The overall mechanical configuration of RISAT-1 is simple and efficient. It also satisfies the envelope and Centre of Gravity (CG) constraints/requirements of the launch vehicle. PSLV-XL was the launch vehicle for RISAT-1 spacecraft.

Stowed configuration of RISAT-1 at the launch pad inside Polar Satellite Launch Vehicle (PSLV) is shown in Figure 2 and the deployed configuration of RISAT-1 is shown in Figure 3.

RISAT-1 design

Structure

The structure is designed to meet the stiffness, strength and pointing requirements of the payload, sensors and also confining the overall bus volume within the launch vehicle envelope. It is based on a single bus concept built around a central cylinder. A truncated triangular structure is built around the cylinder to hold the SAR antenna and major bus service elements. A cuboid structure is built on top of the cylinder to accommodate the solar arrays, majority of the sensors and antennae. The primary structure consists of a central cylinder, interface rings and shear webs. The central cylinder is of sandwich construction with aluminium core and carbon-fibre-reinforced polymer (CFRP) face skin. It has an aluminium alloy interface ring at the bottom to interface with the launch vehicle. The cylinder also provides interface for the propellant tank and reaction wheel deck. Secondary structures consist of equipment panels/decks of the payload module and the cuboid module.

The payload module structure consists of three equipment panels, three corner panels and top and bottom deck. All the equipment panels and corner panels of the payload module are made of sandwich construction with aluminium core and aluminium face skin, whereas the shear webs are made of sandwich construction with CFRP face skin. The triangular decks carry the hold-down brackets to hold the SAR antenna in launch configuration.

The SAR antenna is comprised of three panels, of which one is fixed and the other two are stowed onto either sides of the triangular structure during launch and are deployed in the orbit. Tile Substrate and Panel Frame are two basic structures over which the SAR payload is built. The radiation patch antennae are bonded on one side of the Tile substrate and the Tile electronics mounted on the other side of the substrate. Four Tiles form a panel for the SAR antenna. To support these four Tiles, a framed structure is evolved. Most of the sensors, antennae, solar arrays and their associated electronics are mounted in the cuboid module. RISAT-1 main structure is shown in Figure 4.

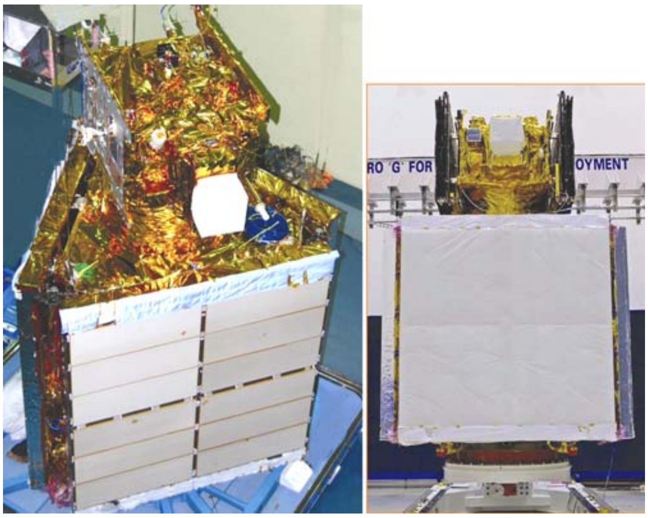

Figure 2. Stowed configuration of RISAT-1.

Figure 3. Deployed configuration of RISAT-1.

The subsystem layout has been evolved considering various factors like electrical requirements, interfaces among various subsystems, physical size and location feasibility, look angle and field-of-view (FOV) requirements of various elements (payloads, sensors, antennae), thermal requirements, mechanical loads, transmissibility factors, physical parameters and balancing, ease of assembly/dis-assembly and accessibility during assembly, integration and testing (AIT) and pre-launch operations. All the subsystem electronics packages are accommodated on the equipment decks/panels.

The payload module (triangular structure) accommodates most of the mainframe systems and the payload electronics. The cuboid module accommodates solar arrays, most of the sensors and antennae, viz. Digital Sun Sensor (DSS), Solar Panel Sun Sensor (SPSS), Earth Sensor (ES), 4π Sun Sensors, PAA, TTC Antennae and Satellite Positioning System (SPS). All the Reaction Control System (RCS) components are accommodated on one of the shear webs and the exterior surface of the triangular bottom deck. The propellant tank is mounted inside the main cylinder. The reaction wheels are mounted on a circular deck in a tetrahedral configuration. The circular

Figure 4. RISAT-1 main structure.

deck is accommodated inside the main cylinder below the tank and is connected to the cylinder through a ring.

Thermal system

Thermal design should maintain the temperatures of the subsystems within design limits during all conditions of operation, all seasons and throughout the lifetime of the spacecraft.

The configuration and equatorial crossing time of RISAT-1 are different from other satellites in the IRS series. Though it is an earth-oriented satellite, during payload operation the satellite will be rotated by ± 36° about roll axis. This new configuration, orientation and equatorial crossing time result in new external load patterns and extreme load conditions which are different from other IRS satellites. Moreover, a number of heat dissipating packages are accommodated inside the structure.

Thermal control is provided using space-proven thermal control elements such as optical solar reflector (OSR), multilayer insulation (MLI), paints, thermal control tapes, quartz wool blanket, sink plates and heat pipes. In addition, heaters will be provided to maintain temperatures during cold conditions.

Mechanism

RISAT-1 spacecraft employs SAR antenna deployment mechanism and solar array deployment mechanism. SAR antenna and solar array are stowed during the launch and are deployed in the orbit in order to meet the constraints imposed by the launch vehicle. In order to perform deployment in the orbit, a hold-down and release mechanism is employed. The solar array deployment mechanism is identical to earlier IRS missions.

The deployed SAR antenna has dimensions of 6.29 m × 2.09 m × 0.220 m. It consists of three panels out of which one is rigidly attached to the triangular structure. In the launch configuration, the deployable panels are folded over the triangular structure and are held by using a hold-down mechanism. In the orbit both the deployable panels are released sequentially and deployed. The mass of each panel is about 290 kg.

Electrical power system: The power system consists of solar array for power generation, chemical battery for power storage and power electronics for power conditioning and distribution. It is designed to meet the 6 a.m./6 p.m. orbit illumination conditions, large power requirement of SAR payload and solar eclipse conditions during summer solstice.

The solar array consists of six panels arranged in two wings with three panels in each wing in positive roll and negative roll axes. The array consists of multi-junction cells connected in series and parallel for optimum configuration. The solar array drive assembly helps in compensating the roll bias (± 36°) given during payload operation and also aids in obtaining more generation near pole transit.

The energy storage system for RISAT-1 employs a single NiH_2 battery of 70AH capacity to meet the peak load requirement and also the eclipse requirement.

It is a single-bus system operating at 70 V and the configuration is arrived at to meet all the requirements of users and interfaces. During the sunlit period, the array is regulated to 70 V and the battery gets charged. A Battery Discharge Regulator (BDR) supports power to the bus when the load demand exceeds the array generation during payload operation and eclipse conditions by regulating the bus to 70 V. Bus voltage selection is mainly driven by payload requirement. The single bus of 70 V is fully protected against over voltage, over current and is single-point failure proof. The bus is distributed to all users through fuses, centrally located in fuse-distribution packages. Software Logics (software resident in the on-board controller) enhances the safety of the power system.

On-board computer

In order to minimize power, weight and volume, the spacecraft functions like commanding, housekeeping (telemetry), attitude and orbit control, thermal management, sensor data processing, etc. have been integrated into a single package called On-board Computer (OBC), which also implements the MIL STD 1553B protocol for interfacing with other subsystems of the spacecraft (Figure 5).

The use of MIL STD 1553B interfaces between OBC and other subsystems greatly decreases the volume and mass of cabling, and the associated connectors. The OBC system is realized with the functions of sensor electronics, command processing, telemetry and house-keeping, attitude and orbit control and thermal management. Besides, the OBC interfaces with power, telemetry–telecommand (TM–TC; RF) for command and telemetry, sensors, heaters, thrusters and reaction wheels through special logics.

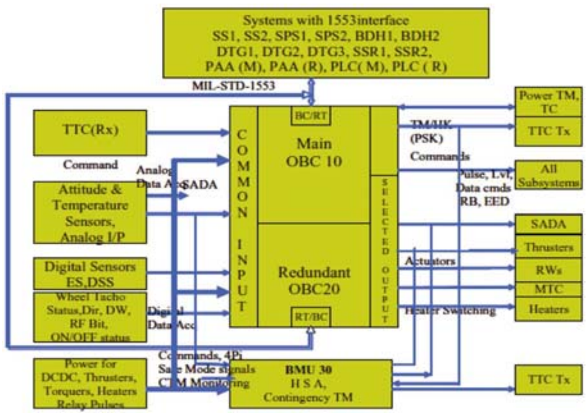

Figure 5. Block diagram of on-board computer.

Integrated control subsystem: AOCS specifications during imaging are as follows: pointing: ± 0.05° (3σ); drift rate: ± 3.0e-04°/s (3σ).

The AOCS configuration is as follows: The attitude orbit control system for RISAT-1 is configured with 4π Sun Sensor, Magnetometer, Inertial Reference Unit (IRU), Star Sensor, Earth Sensor, Digital Sun Sensor and Solar Panel Sun Sensor. Acutators are eight numbers of canted 11 N thrusters (mono propellant hydrazine system operating in blow-down mode) with two-axis canting from + pitch axis for acquisition and OM operation, 1 number of central 11 N thruster for OM operation, 4 numbers of reaction wheels (of capacity 0.3 Nm torque and 50.0 NMS) mounted in tetrahedral configuration about – pitch axis and magnetic torquers of 60.0 A m^2 capacity for momentum dumping. Sun sensors, star sensors and magnetometer provide attitude data in the form of absolute attitude errors. The magnetometer, 4π sun sensor and temperature sensor data are processed in OBC. All AOCS software modules are implemented in OBC.

Reaction Control System

The reaction control system comprises propellant tank, thrusters (9 numbers of 11 N), latch valves, fill and drain/vent valves, pressure transducers, system filters, thermocouples, flow control valves and titanium tubes to connect all the reaction control elements. Block schematic of reaction control system is given in Figure 6. One central 11 N thruster is meant for orbit control and the remaining eight 11 N thrusters for attitude control.

Telemetry Tracking and Command Subsystem

The Telemetry, Tracking and Command (RF) system for RISAT-1 consists of two chains of Phase Locked Loop (PLL) coherent S-band transponder connected to a common antenna system. The basic configuration is identical to the ones employed in earlier IRS missions. The TC demodulation scheme is phase shift keying (PSK)/pulse code modulation (PCM) with a date rate of 4 kbps. The transponder consists of a receiving and transmitting system and can operate in either coherent or non-coherent mode. Range and two-way Doppler data from the transponder are useful for orbit determination.

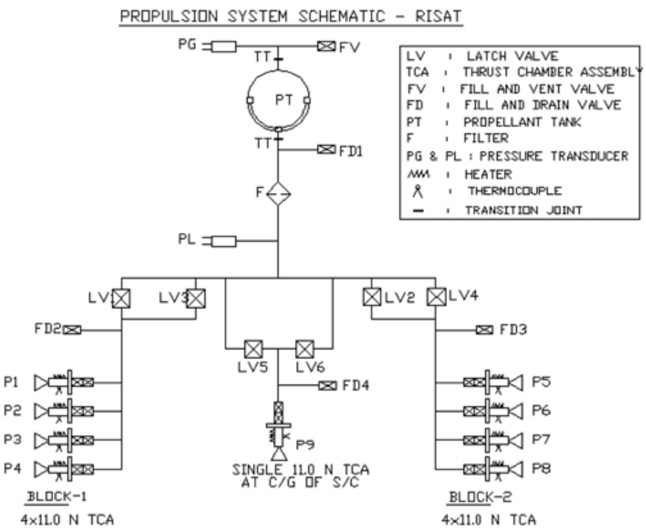

Figure 6. Block schematic of reaction control system.

Payload Data Handling Subsystem

RISAT-1 payload data need to be transmitted either in real time or in playback mode depending upon the data rates at different modes. The data-handling system of RISAT-1 is configured with two formatters for each of the SAR payload receivers respectively (Figure 7).

They are high data rate formatters for different data rates of payload with memories for burst data formatting. Systems have been realized by field-programmable gate arrays (FPGAs) and the design is optimized for weight, power and volume. When the data rate of SAR payload and BDH overhead together is greater than 640 Mbps, real-time transmission is not possible and the data is recorded in SSR. Recorded data can be played back later. Data handling system can operate in real time, real-time stretch mode, record and playback modes.

Solid State Recorder

The RISAT-1 Solid State Recorder (SSR) has a capacity of 300 Gbits, realized with six memory boards of 50 Gbits capacity each. The memory boards, by default are configured into two partitions each of 150 Gbits with three memory boards per partition. The SSR has two control units for configuring and controlling the internal operations. The controller has two separate 32-bit parallel interface with memory boards. The default configuration

Figure 7. Payload data formatters.

is for two partitions; however, the system can be configured for single partition with allocation of all the memory boards to the selected partition. The SSR is able to manage up to 32 different files for each input port.

The memory management guarantees the usage of all good devices by automatic configuration after the diagnostics command is issued.

The allocation of address during recording is managed by the SSR and ground control will not be possible. Erase operation of files is carried out by a command with the file identifier. Playback with segment erase is also one of the options wherein the segments played back shall be released, with a gap of one segment. The record operation depends on the available free space in the SSR capacity. It is possible to read the data files in any order and any number of times. The bit error rate (BER) at SSR level is better than 1×10^{-12}.

The memory plan is constituted by four physical levels, namely memory device level, memory module level, memory bank level and board level and partition level.

There are a total of six memory boards which can be switched ON/OFF by command.

X-band RF

The X-band RF is required to accept the payload data from the baseband data handling system, modulate the above data on two X-band carriers and transmit the same to the ground after suitable amplification and filtering.

The SAR payload of RISAT-1 when operated in dual polarization imaging mode generates data at the rate of 640 Mbps and this needs to be transmitted to the ground stations. Data rates up to 170 Mbps have been transmitted at X-band using shaped beam antenna in earlier missions like IRS-1C/1D and PAA in Technology experiment satellite. In order to meet the high data rate transmission requirement in X-band quadrature phase shift keying (QPSK) modulation with frequency reuse by polarization discrimination is implemented.

In the data transmission for RISAT-1, half the data, i.e. 320 Mbps will be transmitted in right-hand circular polarization (RHCP) and the remaining 320 Mbps in the left-hand circular polarization (LHCP); two identical chains operating at X-band are used to transmit 640 Mbps of payload data. The carrier generation section, QPSK modulator section, filter units, selection of main and redundant chain units are identical in all the chains as the frequency of operation and modulation schemes is identical. Both the chains have end-to-end redundancy.

Phased Array Antenna

The spherical PAA has radiating elements distributed almost uniformly on a hemispherical surface. It generates a beam in the required direction by switching 'ON' only those elements which can contribute significantly towards the beam direction. It is proposed to use the 64 element array.

Operationally it consists of two identical phased arrays, one operating in RHCP and the other operating in LHCP, and located in the same hardware. On the spherical dome an element is located at a defined location. A waveguide radiating element fed by a septum polarizer is planned and this has two ports, one for RHCP and the other for LHCP. The radiating element is optimized to provide the required isolation (better than –25 dB) between the two polarizations to minimize the interference.

The RHCP and LHCP ports of the phased array are connected to two separate sets of power dividers and monolithic microwave integrated circuit (MMIC) amplifiers. A common beam steering electronics controls the switch position and phase setting for all the MMIC amplifiers. Data transmission chain is given in Figure 8.

Satellite Positioning System

Satellite Positioning System (SPS) for RISAT-1 comprises 10-channel C/A code GPS receiver at L1 (1575.42 MHz) frequency. SPS is designed for computing the state vector of the high-dynamic platform.

SPS for RISAT-1 will have full-chain (end-to-end) redundancy. Each chain consists of a receiving antenna, low-noise amplifier, RF amplifier and power divider in L-band followed by a 10-channel and 8-channel GPS receiver with MIL 1553B interface. Each GPS receiver consists of two high dynamics GPS receiver core engine (RCE) modules to compute state vectors and one receiver chain will be active at a time.

SPS is placed in RISAT-1 to track GPS signals continuously. It requires an antenna system with hemispherical radiation coverage to receive the circularly polarized GPS signal from the navigational satellites. Micro-strip patch antenna is used for this application.

RISAT-1 specifications, new elements and challenges

For all the new elements, the concept was proved with developmental model followed by qualification model and flight model. Baseline design review (only for new elements), preliminary design review, detailed design review have been conducted for all the subsystems and the recommendations have been implemented successfully. Preliminary design review and critical design review were conducted for the space segment and the ground segment. Thermal analysis, derating analysis and failure mode, effects and criticality analysis (FMECA) were carried out for all the subsystems and suitable measures have been adopted. Fabrication procedure/new processing has been followed after due approval by the Material

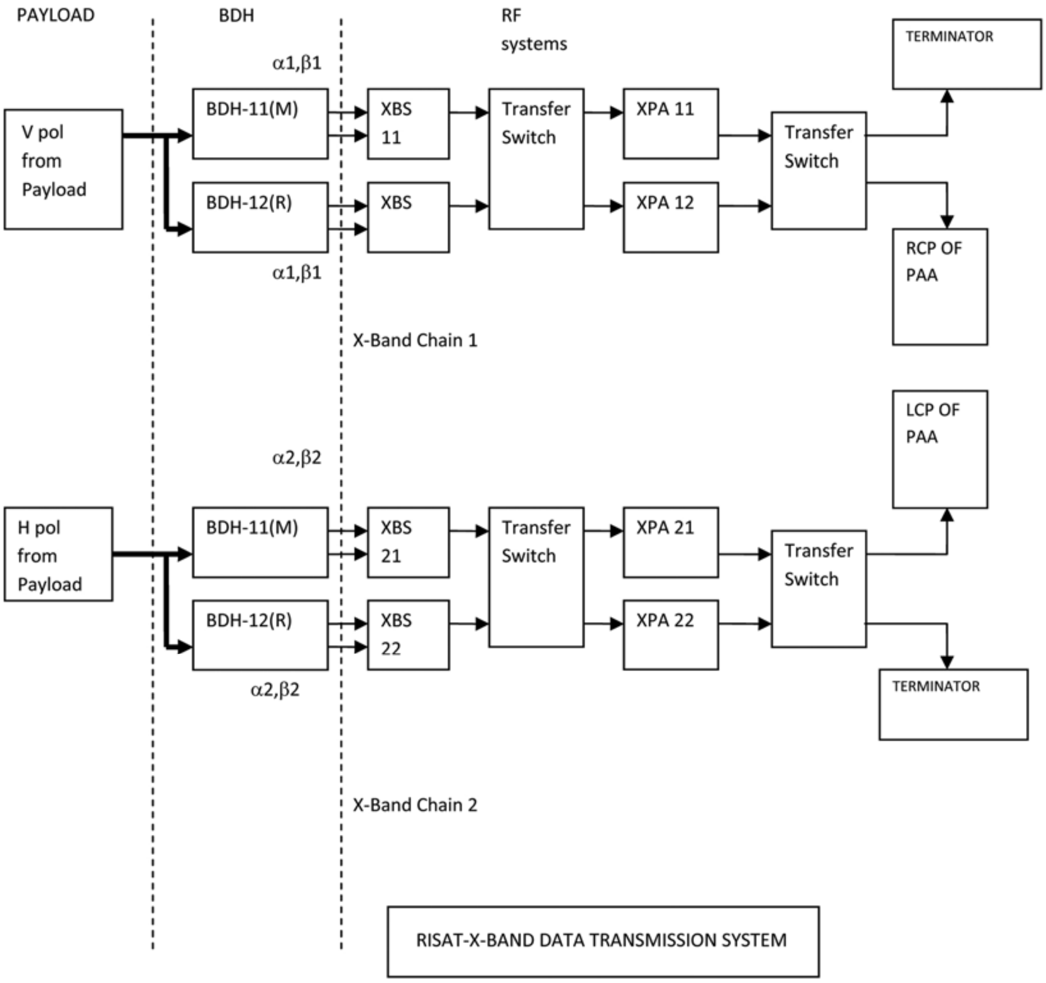

Figure 8. Data flow from SAR payload to Phased Array Antenna.

Table 1. RSIAT-1 Major specifications

Orbit	536.38 km, 6 a.m.–6 p.m.
Inclination	97.554°
SAR payload	C-band (5.35 GHz)
SAR payload operating modes	CRS, MRS, FRS1, FRS2, HRS (with linear and circular polarization)
Resolution	1–50 m
Data rate for transmission	2 × 320 Mbps
SSR	240 Gbits
TT&C	S-band
Payload down link	X-band (frequency reuse)
Power	Regulated bus 70 V/42 V/U-bus
Battery	70 AH
Telecommand	4 Kbps PSK
Telemetry	4 Kbps PSK
Satellite mass	1858 Kg

Review Board. Test and evaluation results of all the subsystems were submitted for review.

Total number of RISAT-1 subsystems were 1300 (approx.) with many controllers, DC–DC converters, high frequency and high dissipating packages, a variety of interfaces (MIL STD 1553 B, RS 422, RS 488, LVDS), RF cables, power lines and control signal lines which demanded proficiency in carrying out the assembly integration activities. Disassembled configuration to assembled configuration was executed faultlessly. Testing the microwave payload and the related mainframe elements was quite taxing at all test phases and SAR testing called for antennae panel in deployed condition.

Handling RISAT-1 satellite which is the heaviest satellite of mass 1858 kg in the remote sensing satellite class and high power of 4200 W at all test phases, was the biggest task. Thermovac test posed a big challenge for the team. The spacecraft was positioned inside the thermovac chamber in deployed condition with thermal instrumentation (Figure 9). The thermovac test was conducted successfully.

Special tests, namely radiation, EMI/EMC, RF compatibility, wheel interaction test with main structure (by hanging the satellite in on condition with wheels operation) and polarity test were conducted. The satellite underwent vibration test and acoustic test in the new acoustic test facility at ISITE. Pre-launch test at SHAR was executed smoothly. Fuel filling was the final activity before PSLV mating and was executed accurately as the mass of RISAT-1 had to meet the requirement of PSLV. RCS performance was critical for raising the orbit to 536 km from 436 km. Data reception, data processing and data product generation (first of their kind) are being executed earnestly.

Performance of RISAT-1 system

After mating with PSLV, launch base configuration of RISAT-1 was selected according to plan. PSLV had injected the spacecraft into 436 km orbit. Solar arrays and SAR antenna panels were deployed by snap command according to mission requirements soon after the spacecraft separation from PSLV. The performance of the mechanism systems is listed in Table 3.

Table 2. RISAT-1 new elements

Subsystem (no heritage)	Highlight
SAR payload	Based on TR module architecture
Structure	Triangular prism, cuboid module, tile frame, tiles, etc.
Thermal systems	Designed for 6 a.m.–6 p.m. orbit
Mechanism	SAR antenna deployment for 300 kg panel
Reaction wheels	50 NMS angular momentum and 0.3 NM torque for mission manoeuvre
Power	70 V bus high power (4.2 KW)
Battery	70 AH NiH_2
BDH	320 Mbps (variable data rate)
X-band system	High data rate modulator 320 Mbps
Phased array antenna	Wave guide antenna with RHCP and LHCP
SSR	300 Gb with high data rate handling

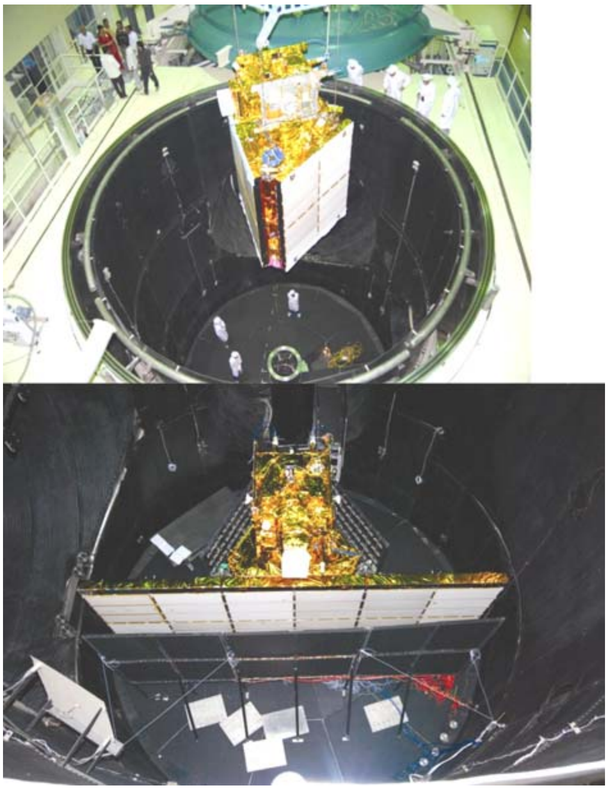

Figure 9. RISAT-1 spacecraft in thermovac.

Orbit manoeuvres were carried out to raise RISAT-1 from the present orbit to 536 km and also get it ready for operational services. Reaction control system completed its task according to design. The fuel available on-board is estimated to be 53.485 kg. Considering all aspects of fuel consumption, the RISAT-1 can be expected to have a useful life of more than design value. SPS data is the primary mode of orbit determination for this mission and the performance of the same is satisfactory.

On-board computer performance is normal. Launch phase sequencer operations for deployment of solar array and SAR panels were executed successfully. Initial acquisition with inertial acquisition (IAC) mode and later earth acquisition operations were normal. Safety logics are enabled. Interfaces with sensors, actuators, power and thermal systems are functioning well. On-board performance of inertial reference unit (IRU) is satisfactory and all performance parameters are within specified limits.

The telemetry, tracking and command system has been providing health information, access to configuring the spacecraft for various routine operational requirements. The link margins on S-band uplink and downlink are above 15 dB as observed from ISTRAC ground stations. The telemetry data storage and SPS data storage system is operated routinely in every orbit to assess the health of the spacecraft even outside the network visibility.

Solar array power generation is 2100 W and power generation started right after the heat shield separation. The power system has been generating, conditioning and supporting the various load requirements of all the systems. Battery supported the launch, all the initial operations like orbit manoeuvres and payload operations successfully, and support continues subsequently for payload operation and eclipse conditions. Battery charging operation is automatically taking place according to the set rate and charge termination voltage. Power system performance is normal and all modes of payload operations are well supported.

Attitude and orbit control system (AOCS) has been performing well in the three-axis stabilized mode. Various modes of AOCS have been exercised and the performance is normal. Four reaction wheels, two gyros and a star sensor with corresponding control electronics have been maintaining the attitude of the spacecraft within the specified limits. Earth sensors are used for safe mode detection. Spacecraft rates during three-axis acquisition are given in Figure 10. Attitude performance during first payload operation is given in Figure 11.

A summary of AOCS performance is as follows:

- Pointing out errors during imaging within 0.0034°.
- Residual S/C body rates during imaging:
  yaw: 3×10^{-5} deg/sec, roll: 5×10^{-5} deg/sec,
  pitch: 2×10^{-5} deg/sec.

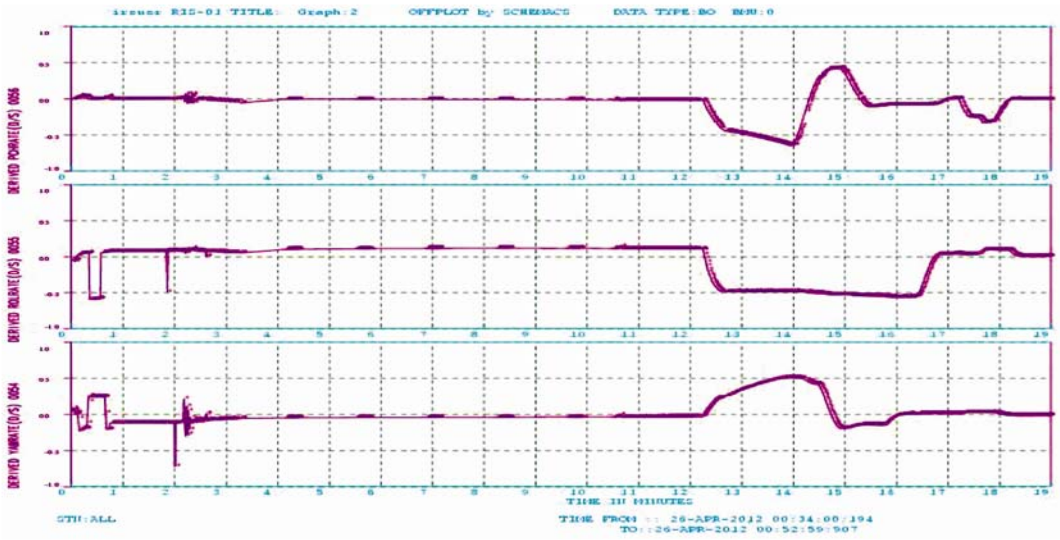

Figure 10. Spacecraft rates during three-axis acquisition.

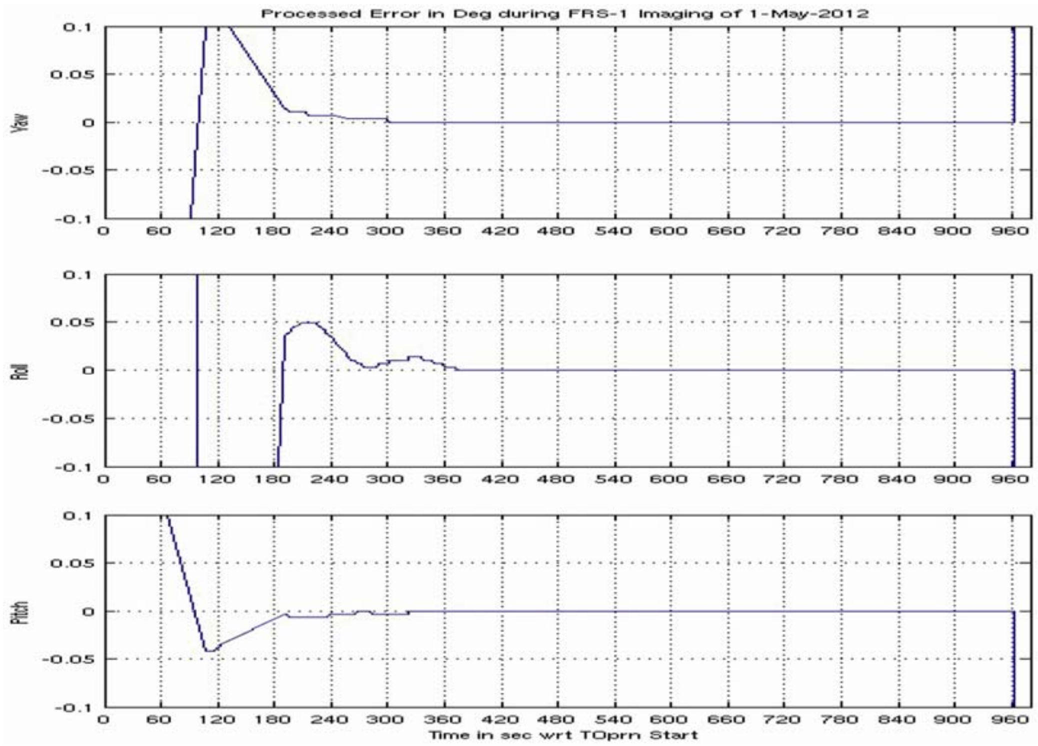

Figure 11. Attitude performance during first payload operation.

- S/C pointing error as measured by star sensor: yaw: 0.03°, roll: 0.01–0.04°, pitch: 0.05–0.08°.

On-board performance of all four reaction wheels is satisfactory. Wheel current and bearing temperature are within specified limits. Wheel speed during payload operations is according to expectation (Figure 12).

Thermal performance of RISAT-1 spacecraft is normal and as expected. Temperatures are stable. Functioning of all thermal control elements (253 temperature sensors, 133 heaters, 54 heat pipes, 13 m^2 of quartz wool blanket, MLI, OSR, thermal control tapes, heat sink plates) is normal and as expected. Temperatures of spacecraft and on-board systems are matching closely with the predicted values for on-orbit cold season. ATC heaters for payload, battery, RCS elements, wheels, SSR, BDR, PAA and cuboid are enabled and operating with predicted duty cycles.

RISAT-1 has been functioning satisfactorily and the in-orbit operations are being executed according to plan. The mainframe has been supporting the payload operations and the SAR payload is sending quality pictures

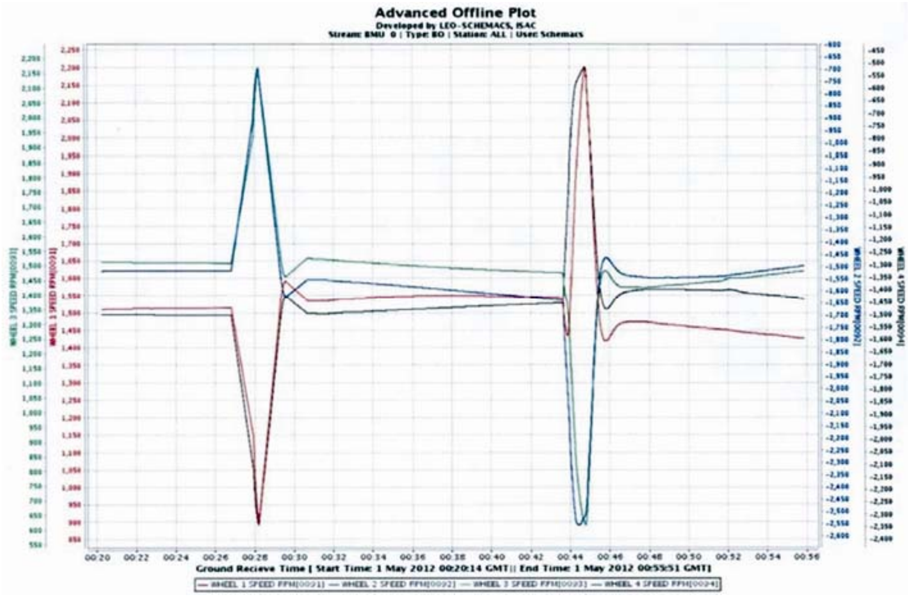

Figure 12. Speed of wheels during payload operations.

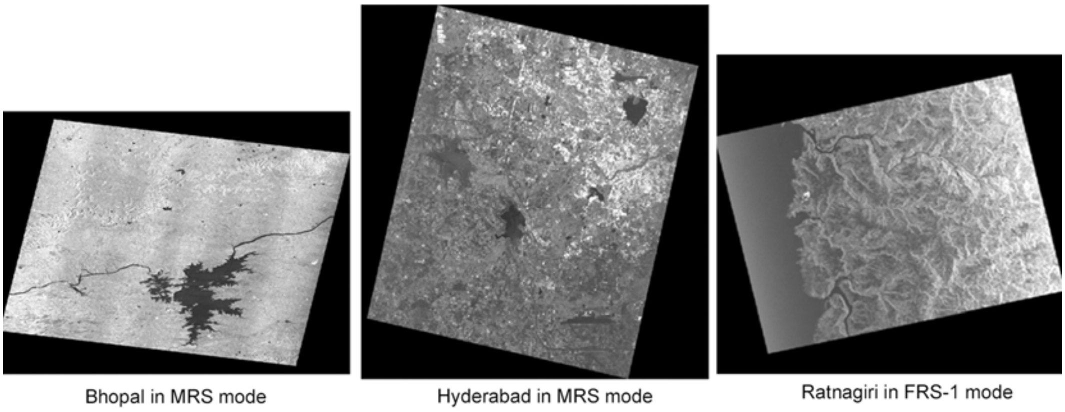

Figure 13. Sample of RISAT-1 images.

Table 3. On-orbit performance of the mechanism systems

Subsystem	On-orbit predicted deployment time (sec)	Actual on-orbit deployment time (sec)
P2-SAR antenna	87	87.17
P3-SAR antenna	81	80.89
+ Roll solar array	6.8	6.4
– Roll solar array	6.6	6.34

during morning and evening passes over India. Various modes of payload are carried out in sequencer mode (auto) through timers which are set prior to the intended operations by the spacecraft control centre personnel. All special requests and events of importance in and around India are being covered. Sample data products of FRS 1 and MRS are given in Figure 13.

The X-band data transmission link has been performing satisfactorily and the margin established during initial phase is still valid and satisfactory.

Conclusions

With the launching and operationalization of RISAT-1, India has emerged as one of the few counties in the world with a capability of using satellite-based microwave remotely-sensed data for various resource applications on an operational basis. The capabilities of RISAT-1 are comparable with other contemporary satellite missions. RISAT-1 has thus laid a strong foundation for the future of microwave remote sensing activities in the country. Advanced versions of SAR missions will provide the continuity of RISAT-1 services to the user community in India in the coming years.

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