

Satellite Technology

Pushing Demand for Skills

The recent decision to allow private industry to venture into the space sector will not only enhance India's share in the expanding global market, it will also create a demand for skills and expertise from several domains.

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THE government of India recently allowed private industry to venture into the space sector. The aim is to enhance India's share in the expanding global market. This shall create new talent, skill and bring in foreign exchange.

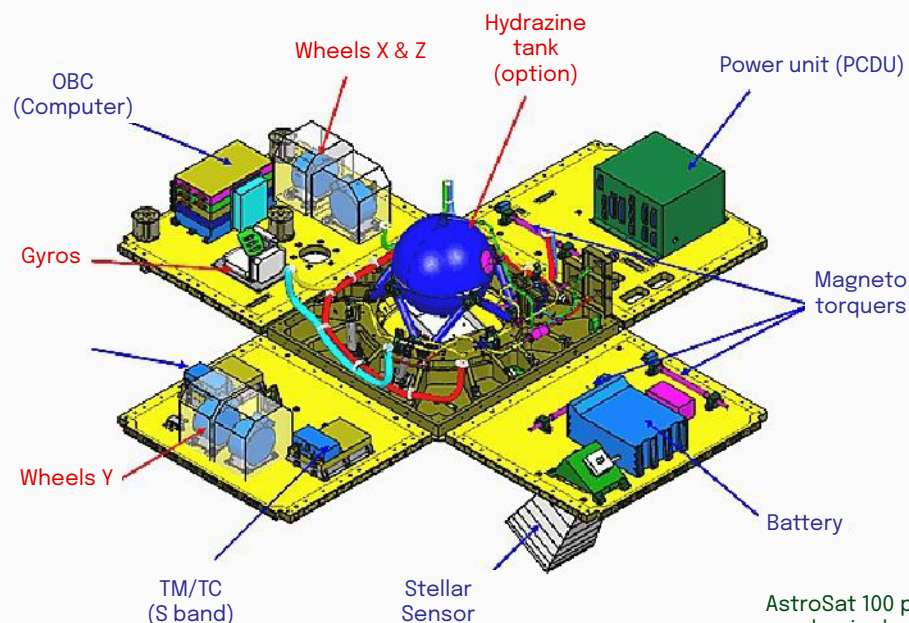
Satellite technology is a multidisciplinary field. There is a piece of pie for the interested. Various sub-systems are integrated to make a satellite. It is realized using several advanced technologies that are autonomous, efficient, reliable, light, miniaturized, and so on. In other words, to make satellite technology really effective, knowledge and expertise of engineers working in several domains are required.

Autonomy

The core of satellite technology is electronics. The onboard architecture has a control unit that makes the satellite nearly

autonomous or independent of manual operations. It has redundancy wherever possible. Human missions are carefully planned with fourfold redundancy besides the configuration being suitable for human safety all through the mission until return.

The various hardware sub-systems need to be appropriately operated and without time delay — the control system does just that. The best architecture is the Field Programmable Gate Array (FPGA). Here, the multipurpose microchip can be programmed or reprogrammed for multiple applications, that is, easily configurable after manufacturing. This is cost effective than the tailor-made Application Specific Integrated circuit (ASIC). FPGA essentially interconnects logical blocks (which also perform mathematical computations) with the input and output blocks. This enables collective functioning of various sub-systems.



AstroSat 100 platform with mechanical accommodation of elements
(Image credit: Astrium SAS)

The control unit when combined with a processor makes it versatile and is widely used in low-cost satellites and is called Onboard Computer (OBC). The control unit that is designed to be scalable or adaptable to any additional demands of satellite capabilities is of strategic importance in the business. The OBC calls for modular hardware and software skills and interfaces. The satellite operations software system needs to follow IEEE standards and has to be fault-tolerant. Embedded technology is also seen in the control system like the imaging defense satellites while accessing image chips.

The control system accepts commands from the ground to schedule satellite operations or activities. In case of emergency, it goes into the safe-mode. The satellite's health available through the data bus is continuously polled by the control system and is telemetered to the ground. There is an oscillator clock onboard which helps to sequence the operations. The time can also be disciplined with GPS clock. All the events of satellite operations are synchronized to accurate GPS time to maintain worldwide unambiguous operations of the satellite. In the area of navigation satellites, specialized knowledge of atomic timing devices is required to maintain the integrity of broadcast time.

The Earth has natural radiation shields and hence the electronic systems are safe here. But in space, all electronic components need to withstand continuous cumulative radiation dosage made up of low-level charged particles. Hence space fitness requires selecting components that are processed or hardened and made to withstand such radiations. Availability of space qualified components is a big source of concern in satellite technology.

It is important to ensure the reliability of electronics systems. Planned testing before satellite launch ensures normal and stressed working conditions in power, temperature and vibrations. These tests are initially stand-alone and finally integrated. The test performance needs to comply with the specifications of the design.

Environment

When the satellite life is planned to be shorter, commercial components are used instead of hardened components. This greatly reduces the costs. For instance, in a constellation of satellites that offers continuous mission. Satellites that fail are replaced. But launching multiple satellites using launch adapters and managing a formation or constellation over the mission life needs proper costing analysis. A formation is nearly autonomous using the onboard technologies and a constellation is mostly monitored and operated from the ground.

Besides radiation, space is known for large variations in temperatures. The range can be even 500°C. Multilayer insulation with Mylar sheets is helpful. While entering any atmosphere the satellite has to have appropriate heat resistant shielding. Also, thermal separation of the operating sub-systems is taken into account while physically positioning them in the satellite along with the radiators. Yet these passive strategies are not enough when the instruments are highly

sensitive. The control systems have to keep all systems in the range of working temperature all the time by using heat pipes. The exchange of heat using active thermal control is complex. These use a flow of fluids or moving mechanism. Material science is the key in getting insights into the selection of such space elements.

A satellite carries one or multiple payloads. The payloads are tailor-made to achieve the planned mission tasks. These tasks could be communicating, broadcasting the warnings and the navigational data, observation by imaging, receiving distress signals, relaying information or data between two on the ground, carrying out certain robotic tasks, or as an altimeter. Observational satellites can use optical or radar imaging else it can be in situ, like collecting certain deposits. Human mission involves performing experiments under Zero-g.

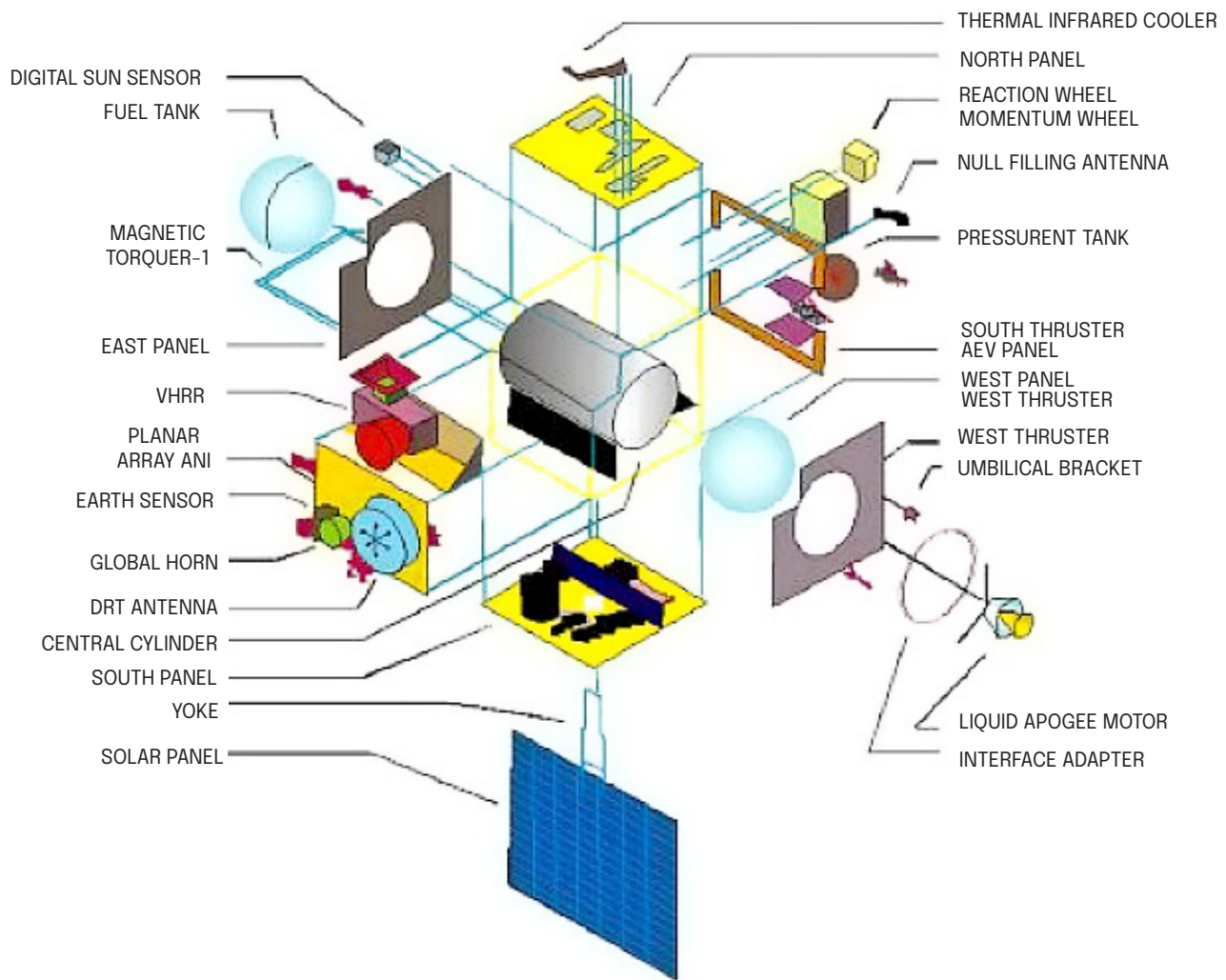
Depending upon the duty cycle or the task load there is a need to provide power to the payloads. Power Distribution Unit (PDSU) design requires knowledge of Power Electronics. It controls failure-free power supply to all sub-systems. Power harnessed is either solar generated or nuclear power. Very few nations have nuclear decay (RTG) to generate power which is very effective in terms of mass and size especially suitable for interplanetary exploration for solar energy. Solar panels with cells are common and are supported by mechanisms that deploy them and slew them towards the sun. These cell structures are sometimes strapped on the body to save mass, especially in small satellites. The cells and the harness need to be space qualified and efficient.

For continuous power supply, the satellites have rechargeable batteries. Voltage stability against varying temperature, charging and discharging capacity is important. Nickel-Cadmium and Lithium-Ion — the former is cheaper but heavier. The general concern of the Power Unit is its mass. The capacity is decided by the duration when the satellite is not powered by Sun and by the depth of discharge — that is the extent of power that can be sourced. For short missions the higher recharge cycles or times that it can be re-charged is overlooked. It is interesting to note that the ground station that receives satellite data also needs continuous power sources.

Data

The satellite health data and the payload data are recorded onboard. They are interleaved and transmitted along with time to the mission station — mostly on Earth or can be relayed through another satellite. Graphic display in making the satellite health conspicuous has progressed thanks to enhanced ground processors.

Data may contain some duplication and has to be carefully attended to on reception. Embedded technology does it faster using digital signal processing algorithms and this enables Quick view of the product. These data are encrypted and compressed before being transmitted and reversed on the ground that has provisions to detect breaks and errors.



Exploded view of the Kalpana-1/MetSat-1: A dedicated meteorological satellite (image credit: ISRO)

The scientific payloads harvest the information about our earth and the universe. Here a complete mission data can be in several terabytes. Science mission data that reaches the interested community throughout the world adopts standard formats like CCSDS. Accurate measurements using highly sensitive payload instruments produce very large data. Human missions require larger bandwidth and need to have continuous real time monitoring.

The transmission of data is sometimes very crucial especially in interplanetary missions where the transmission gets delayed while travelling very long distances even though it is done at the speed of light. This implies a need for proper reference time. Network protocols have to be identified while distributing them secured to users. Costs of these have to be carefully worked out.

A communication satellite has a payload that serves as a broadcaster — it transmits what it receives, like a relay, and this can be information or data. Nowadays communications engineering is much advanced. To illustrate: in using digital

technologies and catering video data with high density along with good ground support or having the capability in receiving with fidelity, at 800 km, the transmitted signal on the buoys employed on sea (used in Tsunami alert). Recently, optical communication has been introduced for Geo satellites and this has enhanced strength, bandwidth and security aspects. LEO satellites have a shorter turn-around time and are suitable for internet applications — as a constellation making it reliable, if not economical.

The transmission of health data through telemetry (TM) and reception of telecommands (TC) are carried out by independent communication systems. Here the link, footprint and frequency capability on the ground are of concern. The first two mentioned conflict with each other as distance increases. Multiple ground stations, matching the frequencies, are terrestrially networked and identified as a part of satellite operations for all the phases of any mission — namely initial, evaluation, normal, emergency and termination. Large ground antennas are slow to steer but easier in tracking the interplanetary satellites.

Control

The payload accomplishes the assigned task by virtue of its position and orientation, also called attitude. The control unit continuously maintains the assigned attitude using guidance. Mathematical design and huge but modular software code enable this. For landing modules, the control has a guidance path of descent. Guidance mostly uses the current and the target attitude. The sensors provide the confirmation while the actuators help in realizing it.

Satellite attitude can be of different kinds: (i) They can be fixed also called inertial hold like a stellar observation from space to eliminate the scattering effects on Earth; (ii) Along with its move or dynamics, it is continuously looking and tracing a path either for communication or imaging, or (iii) It can be looking more at a spot on the Earth, called spotlight mode — this enhances temporal sampling and is sought after in many security applications.

In most satellites, the propulsion systems are of chemical type (producing gas and enabling thrust) for they are capable and reliable for a long mission. Yet, they have lower specific impulse. Bi-propellant systems are normally used for handling heavier satellites while the mono is in smaller ones. They are housed to account the thermal conditions and aligned correctly. Cold gas propulsion has found way into CUBESAT.

The propulsion system and its temperature are continuously monitored by the control unit. This is where Chemical Engineers come in. Ion propulsion using Xenon is used among electric propulsion, can be operated for days and is very useful in maintaining designated orbital track.

Gyros onboard a satellite help to know accurately incremental orientations. The accelerometer measures the velocity due to any external push on the satellite. Earth sensors and Sun sensors provide scalar information, like describing the horizon by its included angles. Sensors need to be aligned conveniently to provide accurate attitude in a mission. Star sensor accuracy is fractions of degree and used on small satellites as they are now compact.

Rendezvous and docking between two orbiting satellites enhance space capabilities and requires relative sensors. They use imaging techniques and laser ranging to determine relative positions and velocity. Inter-satellite communications and transmission of navigation data is mostly employed in refining the relative distances from the sensors. However, when the target satellite is a non-cooperative debris or asteroid then sensor measurement is alone used. Altimeter sensors are useful in measuring heights with respect to the planetary surface and coordinate soft landing. The construction of the test-bed and lab is a challenge for Civil Engineers.

Structure

Processed aluminum alloy is mostly used to tackle debris collision. When the satellite enters the atmosphere or docks or lands the structure is designed to take such impact loads. The structure needs to accommodate various systems in a standard manner. All systems like data, power, fuel engine and thermal systems are accommodated using Computer Aided Drawings.

This makes the interfaces smooth and helps in the modal analysis. Mechanical Engineering discipline helps here.

An extension to the above is the Mechanism system. Here, the control unit with aid of appropriate DC micro motors is operated to deploy or release. They are carried out nearly at the final part of the initial stages like the Solar panels being unfolded or a large gridded antenna reflector being unfurled. Pyrotechnic devices or alternative shape memory alloy aid this release. In the case of docking there needs to be electrical, data and pressure compatibility. The locking mechanism of only one satellite is active at a time. Robotics, deployment of parachute while landing, netting or capturing uncooperative space objects are also required.

Dynamics

Flight dynamics activity enables the payload to be present at the desired position and realise the payload activity. Newton's laws of motion and mathematical modelling of the acceleration fields describe the orbit of the satellite. The launcher provides an orbit which is shaped to achieve the target orbit (more details in *Science Reporter* May 2017).

The tracking station measures range and range rate and estimates the orbit. There is free software like GMAT from NASA that gives a good foothold to understand satellite dynamics before developing one. The flight dynamics enables analysis of the availability of ground facilities and is critical in achieving the mission goals in an optimal manner. Orbit shaping analysis is carried beforehand to know the power requirements, communication opportunities and thermal loads. Orbit tracking and orbit estimation are critical, especially when the satellite is being maneuvered from a lesser gravity field to a stronger gravity field during planetary insertion or landing or vice-versa or while traversing along space manifolds — which assists affordable transport. A lot of mathematical and numerical techniques come into play here.

Mission planning includes carefully reviewing and evolving comprehensive operations strategy in achieving the goals with the payload. All the above-mentioned systems like the control capabilities, thermal and power loads, communication opportunities, orbit achievements and maintenance etc., are examined and cleared for the mission. A baseline design document often helps. After all the systems are integrated, they are subjected to end-to-end tests.

These are just some of the technologies and techniques employed in making satellites ready for launch and for effective performance. This requires inputs from scientists and engineers working in several domains, all coming together to put up an effective satellite technology that can enrich many areas like weather monitoring, national information and health sector.

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