Swanirman Sunirmit Publications of Research Volume 4, Issue 2-Jun 2024 | [2024-25]
ISSN [Online]: 2583-2654

System Engineering approach in configuring a Satellite

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Abstract: Satellites are of different types. Low Earth Orbiting polar satellite or inclined orbit satellite are of one category. The other category is the Geostationary Satellite for Communication / Broadcasting or for Meteorological observation or Earth imaging / surveillance. Each of them have unique configuration and Design approach based on the Service requirements, Payload content and the associated support system requirements. In this article an overview of configuring a Geostationary orbit based Communication / Broadcasting satellite is being discussed.

Keywords: Communication satellites, Payloads, Platform systems, Satellite configuration, Space environment

I. INTRODUCTION

A typical Communication satellite in its fully deployed configuration, located at the Geo Stationary Orbit looks like this.

Fig 1: An artist's view of a Geostationary Communication Satellite

It is a 3-axis body stabilized spacecraft and has two sided solar arrays on the North & South sides for power generation, reflectors on the East & West sides and fixed mounted antenna on the Earth viewing face for telecommunication and / or broadcasting signals. The payloads and the Support (also referred as Bus or Platform) Subsystems are accommodated inside the cuboidal structure. This being the external view let us look into the building blocks of the satellite.

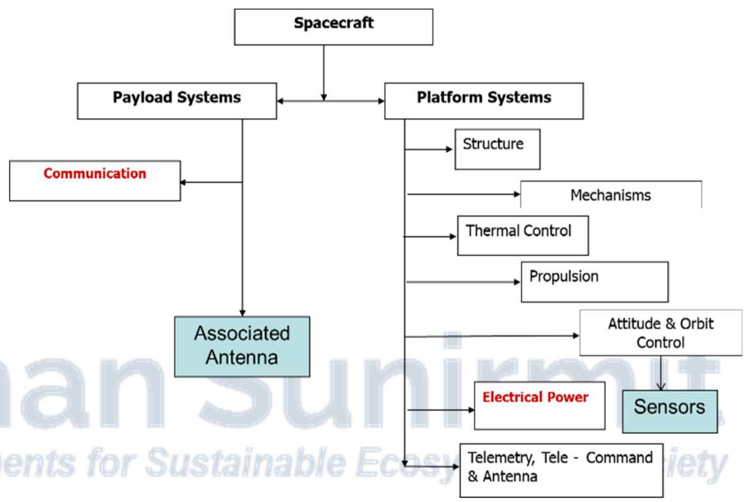

Fig 2: The Block Schematic of a Spacecraft

The blown up features of the satellite appears like

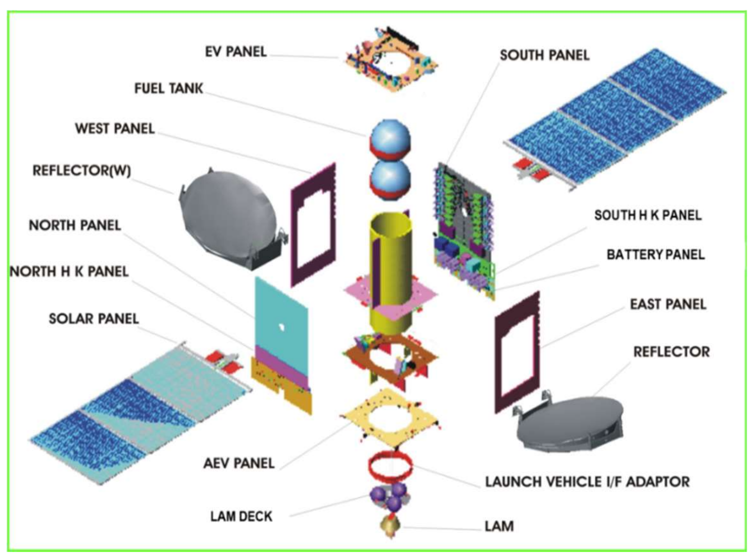

Fig 3: A Typical Exploded view of a Spacecraft

II. CONFIGURATION APPROACH

The Configuration of a satellite begins with the Payload service requirements. Then follows the definition of the Payload content and its configuration. Subsequently the Support Systems are determined and finally the complete Satellite.

The typical list of services from a Communication Satellite would cover basic telecommunication, backhauls of terrestrial mobile communication, business communication in the form of VSATs, broadcasting services (Radio and TV), Broadband services, Societal services like tele education, telemedicine, Disaster management services like search & rescue or simply a data transmit for a Met payload etc.

Broadly the following two Block Schematic explains the approach. The payload services, the performance requirements, co-ordination aspects and the available technologies define the Payload configuration, which further leads to the Spacecraft configuration.

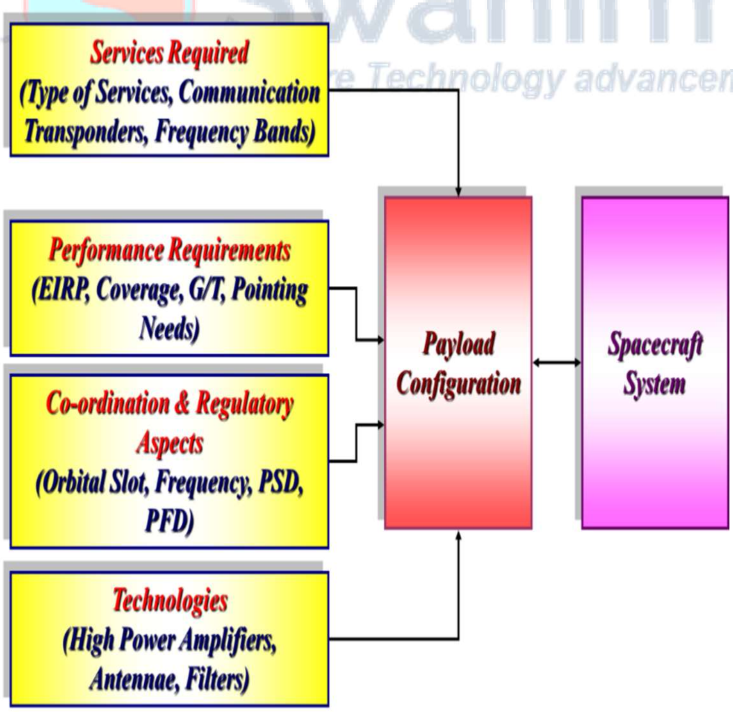

Fig 4: What factors define the communication Payload

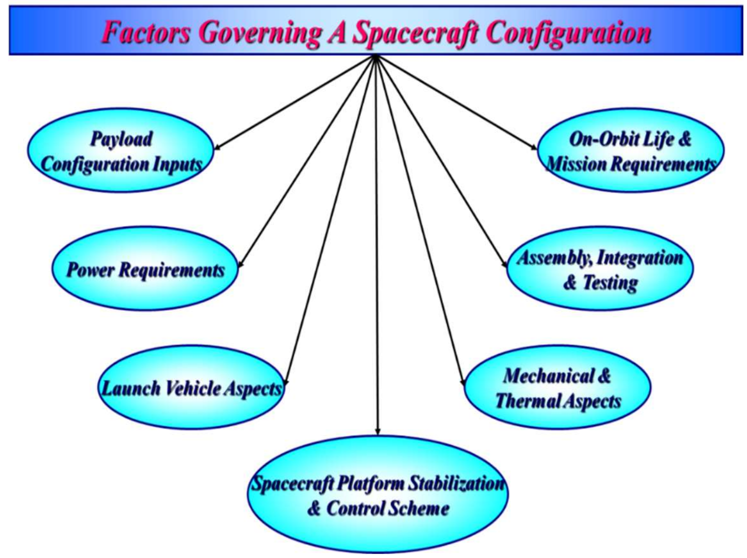

Fig 5

Technologies in the Payload Configuration go to decide the volume, mass, power and thermal dissipation details of the payload.

- ***Payload Technologies***
  - **HPAs – SSPAs, TWTAs**
  - **Cavity Filters, low and high power, Dielectric Filters**
  - **Fixed Mounted, Deployable Reflectors**
  - **Unshaped Reflectors, Shaped Dual Gridded Antenne**
  - **Multiple Beam antenna System**
  - **Beam Steering, Inter Beam switching**
  - **On Board Processing**

While configuring the payload, various aspects related to market potential is assessed, the Govt / international regulations is kept in the background. Overall cost per transponder per year is estimated to validate the economics of the approach.

The Impact of the Payload configuration on the Platform Sub Systems:

The foremost is the Payload accommodation. The equipment panel size is determined to accommodate the various payload subsystems like the Receivers, Input / Output multiplexers, Power Amplifiers etc. The payload mounting area is also a deciding factor for handling the payload thermal dissipation through

ISSN [Online]: 2583-2654

conduction and radiation through OSRs (Optical Solar Reflectors) to the outer space. If the equipment panel area is found inadequate, a deployable thermal radiator panel may be considered. The volume of the payload decides the overall spacecraft size. This includes the deployable reflectors of the payload in the stowed configuration. The reflector protrusions have to be studied with respect to the Launcher Payload fairing sizes (4 mtr or 5 mtr). After assessing the Payload thermal dissipation, decision to use embedded heat pipes or use of basic heat sinks is decided.

The structure is not only for accommodating the payload but it provides the required strength and stiffness for the satellite. It is divided into several functional zones like for payloads, platform electronics, batteries, propulsion system (Tanks and thrusters) and the appendages like the solar arrays and reflectors. The choice of a metallic or a CFRP structure or a mix of both depends on the Payload mass, volume and thermal dissipation inputs. The appendages have a Composite material substrate. Materials such as special plastics reinforced with carbon, Kevlar or glass are employed from mass efficiency & better strength perspectives.

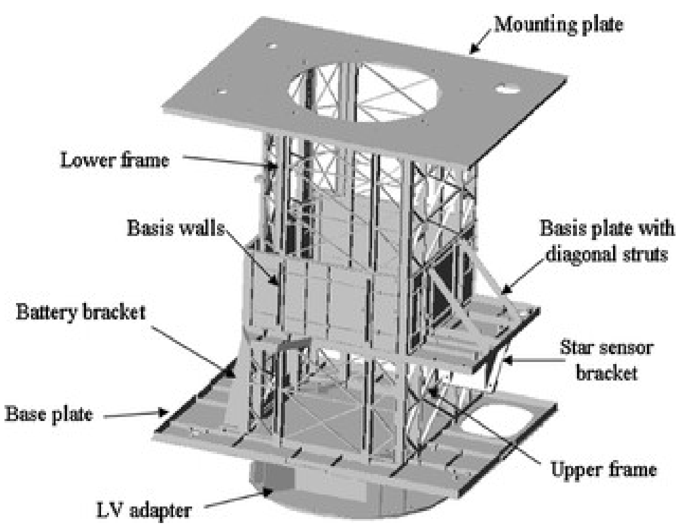

Fig 6: View of a typical satellite structure

The deployment mechanisms are part of the structure whose critical parameters governing its design are, Stability especially during Maneuvers, Satellite and antenna pointing requirements, Good Alignment of the antenna and the sensors, capable of withstanding the variations in the mechanical environment like the deployment & latch-up shocks etc.

As discussed the Thermal system has to maintain nominal Temperature of all Subsystems under all external environments and under all operating modes of the payload like full operation or partial operation, under sunlit or eclipse conditions. Nominally the temperatures to be maintained for different subsystems are - 0 to 40 deg C for Electronics, 0 to 10 deg C for Batteries and -10 to 50 deg C for Propulsion Systems. These temperatures are achieved by passive thermal control and heater operations (in eclipse season).

The propulsion system is for raising the orbit of the spacecraft to its GSO slot and also for in-orbit station keeping (attitude and orbit maintenance). It can be a chemical propulsion based (with oxidizer and fuel) or Electric propulsion in the recent advancements. Many satellites use a combination of both chemical and electrical propulsion as a satellite mass saving effort. In such a case, the chemical propulsion is used for orbit raising and achieving its GEO orbital slot, while the electric propulsion is employed for the In-Orbit maintenance. The Chemical propulsion system typically consists of the tanks for the Fuel, Oxidiser and the Pressurant, Pressure Regulators, Pressure Transducers, Valves, Filters, a combination of larger and smaller Thrusters. The Electric propulsion system will contain a tank for storing an inert gas like Xenon or Argon, the thruster assembly with its combustion chamber and a HV source for providing the accelerating voltage / power for the gases.

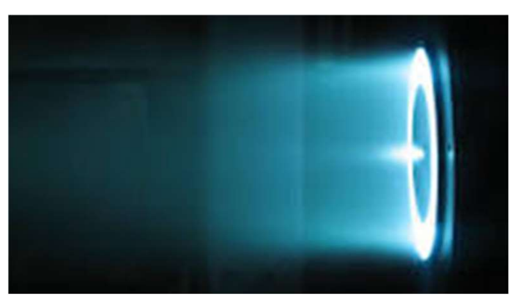
Fig 7: An Ion thruster in operation

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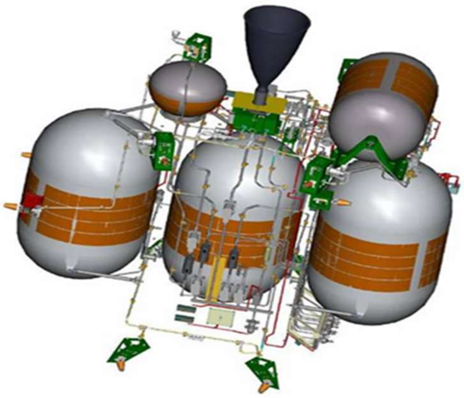

Fig 8: Typical view of the propulsion tanks

The propulsion system decides the Life of the Payload operations or the life of the satellite. The Payload mass will decide the extent of propellant to be loaded for orbit rising and on-orbit operations, which in turn decides the tankage volume and propellant loading. Thus the Life of the Payload services decides the dry weight as well as the lift-off mass of the satellite. This in turn may put restrictions on the choice of the Launcher to be used like our own GSLVs (different versions) or even a procured launch.

The next support system that gets impacted by the Payload service needs is the Power Subsystem. This system consists of 3 major blocks namely the Solar Array for power generation, the Batteries for power storage and the Power electronics essentially for regulation and distribution. The payload power has direct relation to the sizing of the solar array, number of panels in the array and the panel size. As the technology has progressed, we have moved from the 12% (conversion efficiency) Silicon solar cells to 28% Advanced Triple Junction cells. This very much reduces the array size for a given power demand.

As the spacecraft body remains fixed in the Earth viewing attitude (assisted by the Attitude control system), the Solar arrays have to keep tracking the Sun for maximum power generation. This auto tracking is ensured using a Solar Panel Sun Sensor mounted on the array and making it as part of the tracking control loop. The solar power generated from the panel is transferred to the Power Electronics and Batteries mounted inside the satellite cuboid through a rotary power transmission mechanisms called as Solar Array Drive Assembly. Is mounted on the North & South decks of the satellite.

Fig 9: A typical multi panel solar array

Fig 10: Solar Array Drive Assembly

To support the payload operations during the eclipse seasons, batteries become an integral part of a communication satellite. In the age old days, Nickel Cadmium (Ni-Cd) Cell Batteries were employed. But, with the advent of newer battery cell technologies, presently Lithium Ion Batteries are a common feature. They are of lower mass and less voluminous. They have a high energy density per mass ratio of about 90 Wh/Kg. They allow a higher discharge depth up to typically 70%. The battery mass for a 1000W power supply is around 20 Kg as against 80 Kg in the Ni- Cd batteries. The technology is still evolving towards a low mass and high energy density batteries. Below is a representative image of a Ni-Cd and Li-Ion Batteries.

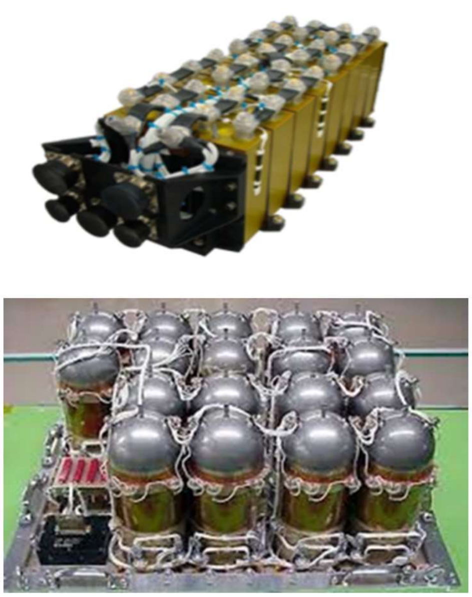

Fig 11

In the GSO, the Attitude and Orbit Control of the spacecraft helps to provide accurate pointing of the communication payload antennas towards the Earth, more specifically over the coverage area. The satellite attitude may get disturbed due to various factors like micro level atmospheric drag, solar wind and radiation pressures, effects of magnetic field interactions, Reactive forces arising out of moving components within the satellite like momentum wheels or gyroscopes, the sun tracking solar array movement and the impact from external forces like micrometeorites etc. These disturbances results in changed attitude pointing of the satellite, which needs to be corrected. The errors in the attitudes in Pitch, Roll and Yaw directions are sensed by optical/ IR / Star sensors and also by the Gyroscope angle readings. A microprocessor with its software evaluates the corrective forces to be applied to the various actuators to nullify the attitude errors. The actuators can be a Magnetic torques or a thruster (either chemical or Ion) or Momentum wheel speed biases etc. The ensemble of the central microprocessor, with its computational logics and the sensors and actuators is referred to as the AOCS, Attitude and Orbit Control System, whose block schematic is as given below.

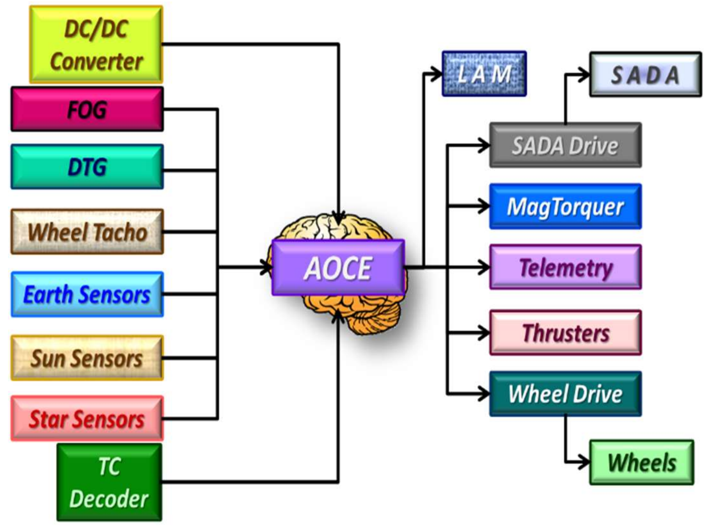

Fig 12: AOCS Functional Block Schematic

Once the Payload reaches its intended orbit in space, its health has to be continuously monitored. Commands need to be sent for payload operations. The functions of health monitoring and commanding is performed by the TTC (Tracking, Telecommand and Telemetry) Subsystem. The Base Band signals are in Digital format. Even if they are analog, they are converted into Digital format. Formatting, digital modulation / demodulation are performed as per a chosen protocol. Encryption and Decryption is included if the TTC functions are to be safeguarded. The signal interface with the ground is through an RF Carrier. Various command types are On/OFF Commands, Data Commands, Time Tagged Commands, Execute after Verification Commanding and Remote Program Based Commanding. The system designer chooses what is required and what is more appropriate. Similarly on the monitoring side, one has Telemetry for Voltages, Currents, Pressure data, Speeds, Deployment Latching status etc. One can have Normal Real Time Telemetry or a Dwell Telemetry in which a chosen parameter is monitored continuously, a Store & Forward Telemetry in case of onboard processing or monitoring when direct line of sight to the spacecraft is not always possible. The extent of payloads will determine the extent of circuits (other than main frame subsystems) to be incorporated in the TTC hardware and accordingly adds to the overhead of mass and volume.

ISSN [Online]: 2583-2654

Thus we have seen how each and every Platform or Bus support system gets impacted by the Payload configuration.

Design and Test for the Space Environment:
Once the spacecraft is fully configured, it has to be ensured to be functional in all the environmental conditions that it is expected to encounter from launch till the end of life. These are related to the Mechanical environment during launch like Acoustic noise, Vibrations and Shock loads, the depressurization during the rocket (along with the satellite) ascent phase, the Thermal environment in the on-orbit operations. These environments are not only addressed during the Design phase, but also ensured through testing of the subsystems and the spacecraft for Vibration (Sine & Random) and Acoustics. Similarly the Thermal design is validated through a Thermovac test and sometimes through a Thermal Balance test. The other environmental conditions like the high energy particle radiation, Electromagnetic radiations, Effect of Plasma arising due to high energy electrons and ions are addressed by providing appropriate Grounding for all electronic equipments, shielding the packages and the interconnecting harnesses for avoiding Electromagnetic Interference, providing bleeder paths to the ground for electrostatic discharges etc. The Contamination effects due to material outgassing, sublimation and similar material properties are ensured at the Parts & Materials level by testing and selection. The spacecraft is built as per the Declared (or Standard) Parts & Materials List. The propulsion plume impingement on sensitive external appendages like Sensors is taken care in the system design.

III. CONCLUSION

In conclusion, a Satellite Design is a System Engineering field involving a multi-disciplinary knowledge of Science & Engineering. It involves a structured design & development process considering various requirements which could be sometimes conflicting, with choices between technological options. Configuration and design approach is by keeping in mind the end product & end application in mind.

In the present days, we have heard about Low / Medium Earth orbiting communication satellites like StarLink, OneWeb, Kupier etc. It is also possible to have come across small satellites, which are mass, volume and power efficient. In all these cases, the Satellite building blocks remain the same, meaning starting with the Service requirements, defining the Payload and building the Payload support systems and finally the Spacecraft. The advancement of technologies enables one to realize the satellites more mass, volume and power efficient. These technologies would include SoC (System on Chip) for the Electronics, Electric / Ion propulsion system, high efficiency solar cells and miniaturized battery, low mass and high strength materials for the satellite structure and Mechanisms etc. Thus we have seen a 250 Kg Star Link satellite and 150 Kg OneWeb satellite. It may be worth recalling that both of them are meant for Mobile Internet applications. Future holds much more interesting technological prospects for the Satellite Building, specifically for Communication.

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