PRATHAM

IIT BOMBAY STUDENT SATELLITE

Preliminary Design Report

System Engineering and Integration

By

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Preface

The System Engineer has the job of seeing the mission of the project as a whole and dividing it into requirements which for each of the Sub-System. One of the interesting paradoxes that the System Engineer often encounters during his work is the level of detail he is supposed to know and grasp about each Sub-System. A System Engineer cannot become a walking encyclopedia for the project; that accurately keeps track of all the little details in each Sub-System. But at the same time, the best design solution will emerge only when the details are taken care of.

Since I am the System Engineer and the Project Coordinator for Pratham, it was decided that I must look at all the Sub-Systems in complete details. This includes attending all Sub-System reviews, checking all technical documentation and reports created by the Sub-Systems. Hence I have to keep myself updated with new literature as we progress in this project. This has helped me immensely in my System Engineering activities since I know all the Sub-Systems in detail. Obviously this method works only for small projects like ours and is not a solution for the above paradox.

Saptarshi Bandyopadhyay
System Engineer and Project Manager
Pratham, IITB Student Satellite

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Chapter 1: Introduction

In this chapter, we will give a brief introduction to the concept of Student Satellite and the work of the System Engineer and the Integration Team.

1.1 Vital Statistics about Pratham

Pratham is the first Student Satellite being built under the IIT Bombay Student Satellite Project. Some of the vital statistics about the Satellite are as follows:

- Weight ~ 10 kgs
- Size 26cm X 26cm X 26cm cube
- LVI from VSSC (IBL230V2)
- Solar Panels on 4 sides
- Orbit – 10:30 polar sun-synchoronous
- 2 deployed monopoles
- Downlink at 2 frequencies (150MHz and 400MHz)
- No uplink
- Completely autonomous

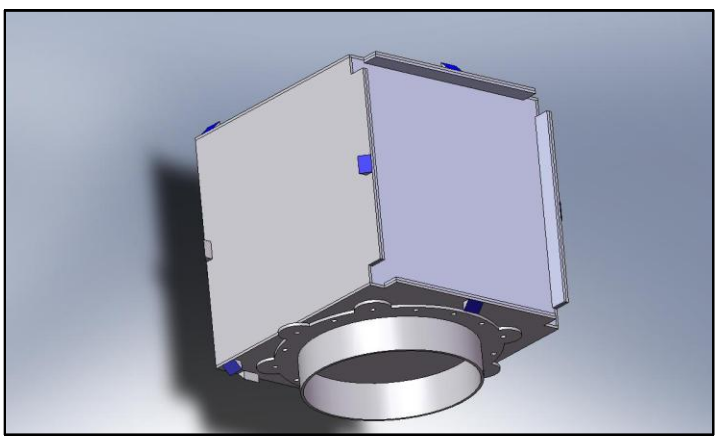


Figure 1: Pratham's Engineering Drawing

1.2 Introduction to Student Satellites

The concept of Cubesats was first proposed by Prof. Bob Twiggs, Space Systems Development Laboratory, Stanford University in 2002. Cubesats were small (100mm X 100mm X 100mm), standardized, low cost and specially built for commercial application. They had low fabrication costs since they used COTS components and had low launch costs as they could be piggy-backed on other launches. They were ideal for low cost, high risk space missions. Moreover, many companies like SSDL, Pumpkin started making COTS components for Cubesats.

Figure 2: Prof. Bob Twiggs

Many universities started exploring the concept of Cubesats. Mission with low cost yet exposure to space technology can be introduced into the curriculum and adequate funding was easily available from industry. Soon universities started launching their own satellites which were called Student Satellites. Student Satellite means students with no prior knowledge in this field, build their own Satellite. Due to various methods of standardization and COTS components, focus has shifted to the Payload and the science objective. As of 2006, about 50 universities all over the word were involved in making Student Satellites.

International Standards for Nanosatellites are available. California Polytechnic's Specifications for CubeSATs are as follows

- No pyro-ordnance allowed onboard the Satellite
- CG must be within 20mm of Geometric Centre
- Rails must be smooth with edges rounded to 1 mm radius, with at least 75% (85.125 mm of a possible 113.5mm) in contact with the P-POD rails and hard anodized (To prevent cold-welding, reduce wear, and provide electrical isolation between the CubeSats and the P-POD)
- Separation springs must be included at designated contact points
- No electronics may be active during launch and CubeSats with rechargeable batteries must be fully deactivated during launch or launch with discharged batteries.
- One deployment switch is required (two are recommended) for each CubeSat

- Testing and battery charging after integration must be through GSE that connects to the CubeSat through designated access ports
- A RBF pin is required which will be removed once the CubeSats are placed inside the P-POD. RBF pins must fit within the designated data ports and not protrude more than 6.5 mm from the rails when fully inserted.
- Antennae may be deployed 15 minutes after ejection from the P-POD (as detected by CubeSat deployment switches). Larger deployables such as booms and solar panels may be deployed 30 minutes after ejection
- CubeSats may enter low power transmit mode (LPTM - short, periodic beacons) 15 minutes after ejection from the P-POD and enter high power transmit mode (HPTM) 30 minutes after ejection
- Operators must obtain and provide documentation of proper licenses for use of frequencies with proof of frequency coordination by the International Amateur Radio Union (IARU). Applications can be found at www.iaru.org.
- Qualification and acceptance testing for integrated S/C-SS system
- No external components other than rails may touch the sides of the PPOD
- Exposed surfaces must be alodyned to prevent corrosion in space environment (Alodyning – Treatment of Aluminum in a dichromate bath to create micron-thick film of chromate coating on surface – Similar to industrial CNC coating)
- Dimensional constraints must be strictly met
- Overall density of the CubeSAT cannot exceed 1 g/cc

Since Pratham (size close to 30cm cube) doesn't fall under the CubeSat category, these specifications are not mandatory for the project. But effort has been made towards meeting these specifications as they are helpful in preventing failure of the spacecraft.

The Poly Picosatellite Orbital Deployer (P-POD) is California Polytechnic's standardized CubeSat deployment system. It is capable of carrying three standard CubeSats and serves as the interface between the CubeSats and LV. The P-POD is a rectangular box with a door and a spring mechanism made of anodized aluminium. CubeSats slide along a series of rails during ejection into orbit. CubeSats must be compatible with the P-POD to ensure safety and success of the mission.

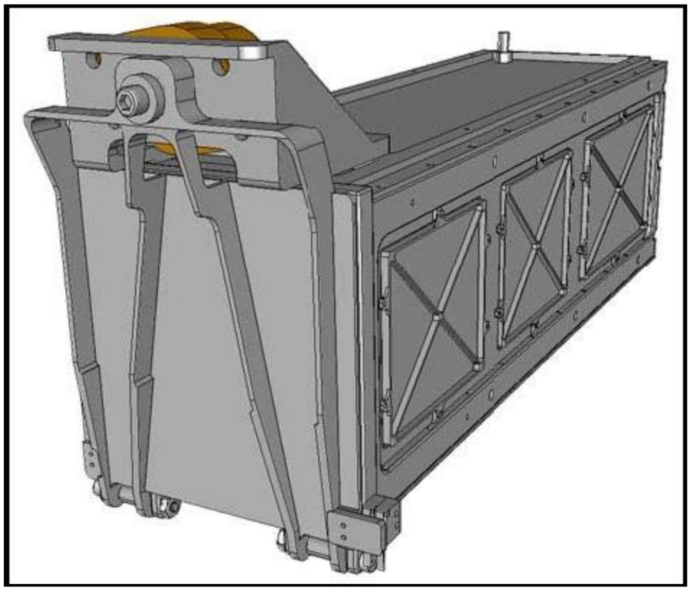


Figure 3: PPOD exterior

Some of the Student Satellites that have been launched till date and we have extensively studied and used their documentation in our initial stages are

1. Mini-Sputnik
2. ASUSAT, Arizona State University
3. NCUBE, NTNU, HiN and NLH , Norway
4. SSETI, 11 universities in collaboration with ESA
5. AAU Cubesat, University of Aalborg, Denmark
6. SNOE, University of Colorado
7. ICARUS, University of Michigan
8. CATSAT, University of New Hampshire and the University of Leicester, England , supported by NASA
9. DTUSAT, Technical University of Denmark, DTU
10. MEROPE, Montana State University, USA
11. COMPASS, Aachen University of Applied Sciences, Germany
12. SEEDS, Nihon University, Japan

During our literature survey, it was found that the cubical Satellite of 30cm egde lengths had the maximum success rate among all the student satellites launched. Hence during the initial literature survey, the Satellite size was fixed to about 30cm cube and weight about 10kgs.

1.3 System Engineer's Tasks

The position of System Engineer is different from all other technical positions in the IIT Bombay Student Satellite Team. All technical positions are aimed at developing the technical know-how needed to make the Satellite. The System Engineer's job is NOT to involve in these technical research and development activities but to ascertain that all of them fit together at the time of System Integration. He is responsible for the success of the 'big-picture'. Hence the focus of System Engineer's work will be majorly on System Integration and System level overview of all other Sub-Systems. The work of the System Engineer for Pratham is listed below and will be explained in detail in the succeeding chapters.

1. Defining the Mission, Success Criterion for the Mission.
2. Defining the System and Sub-System Requirements.
3. Defining the Operational Sequence.
4. Wires and Connectors. Routing of Wires
5. Mechanical harness. Screws. etc.
6. Configuration Layout
7. Integration Sequence
8. Maintaining Budget for all inter-Sub-System quantities.
    a. Weight Budget (for Structures Sub-System)
    b. Power Budget (for Power Sub-System)
    c. Data Budget (for On-Board Computer and Communication Sub-System)
9. Level 2 Testing – OILS
10. Manufacturing process for the structure, Fabrication of the Structure

Since System Engineering is trying to bring all the Sub-Systems together towards the final Mission of the Satellite, the 10 Sub-Systems in Pratham will be introduced first.

1. Payload Sub-System deals with the Payload of the Satellite.
2. Communication and Ground Station Sub-System deals with the communication link between the satellite and ground station. They are in charge of the communication circuits onboard the Satellite and the Ground Station.

3. Attitude Determination and Controls Sub-System deals with determining the attitude and position of the satellite in space and controlling the attitude within specified ranges.
4. On Board Computer Sub-System takes care of all the data processing and storage requirements on board the satellite and it will transmit all the necessary Data and Health Monitoring information to the ground station via the Communication channel.
5. Power Sub-System makes the necessary power available to all instruments on board the Satellite.
6. Structures Sub-System has the job of making a sturdy frame for the Satellite and mounting the various components in it and protecting them from the harsh environments of space.
7. Thermals Sub-Systems has to keep all the electronics within a specified range of temperature so that they can function in space.
8. Mechanisms Sub-System will need to deploy the two monopole antennas in space. They will also design the SNAP circuit which we detect the Satellite has been deployed into space by the launch vehicle.
9. Quality Sub-System shall do Quality Analysis of everything onboard the Satellite. They shall carry out electrical, mechanical and software quality checks of the Satellite to prove that it will function without failure in space.
10. Integration Sub-System has the job of bringing all the above Sub-Systems together to make a complete System.

This report deals with the work done by the Integration Sub-System for the Preliminary Design Phase of the project.

Chapter 2: Mission Statement for Pratham

The Indian Institute of Technology Bombay, Student Satellite Project has an overall plan to launch atleast 5 satellites into orbit within the next few years. The objective of this Project is to make IIT Bombay a respected center for advancement in Satellite and Space Technology, in the world. Hence IIT Bombay should launch at least 5 satellites within the next few years. These Satellites could be test-beds for new technology that is being developed in the institute and need space qualification.

The Student Satellite named Pratham being currently made is the first of this series. After months of literature survey, a Payload was chosen which was deemed fit for the first satellite.

2.1 Mission Statement and Success Criterion

The Mission for Pratham, IIT Bombay's First Student Satellite is

1. Acquiring knowledge in the field of Satellite and Space Technology.
2. Have the Satellite entirely designed by the student body of IIT Bombay.
3. Have the satellite launched, Measure TEC of the Ionosphere above IITB.
4. Involve students from other universities in our Satellite project.

When all the 4 mission statements are fully satisfied, we can call our satellite to a complete success (100%). The IITB Student Satellite Team has attached a lot of importance to all the mission statements. The Success Criterion for the Project is shown below.

Table 1: Success Criterion

Description	Success of Mission
Flight Model ready	55%
Beacon Signal received	65%
Communication link is established	75%
TEC measurements at IITB	85%
Satellite is functional for 4 months	100%

2.2 Annotations of the Mission Statement

Indian Institute of Technology, Bombay is an Educational and Research Institute. It is obvious that a project of this magnitude will give rise to many research opportunities and advancements in technologies. The current learning that is being produced was not available within the institute when the project started. The involvement of faculty members has positively boosted our learning curve and will also ensure continuity in a better manner. The faculty members lead by Prof. K. Sudhakar are involved only in guiding us since it is a Student Satellite, hence the entire work is done by the Students. Hence there are regular reviews and the minutes are noted and stored for future reference.

The future Satellite projects of the institute could become a test-bed for new technological developments within the institute. Some of these technological innovations could also boast of space testing and qualification with the help of this Project.

Finally, all the knowledge that is gained though this project and literature surveys as very precisely documented for future Satellite missions. The new fields that we are exploring right now need not be explored again because all the details are accurately documented. All the documents and minutes are uploaded on our website: www.aero.iitb.ac.in/pratham

The various stages in the development of the Satellite are Design, Analysis, Fabrication and Testing which happen in a cyclic manner. During the Design phase for the Satellite, various System and Sub-System requirements are identified, defined and quantified. The different stages of Design in increasing order of maturity are Conceptual Design, Preliminary Design and Advanced Design.

Once a suitable model is ready and satisfying all the Design requirements, the model is extensively analyzed using simulations. Various simulations are conducted in the field of Structures, Thermals, Power, Communication and Attitude Control. In the phase of Fabrication, the various parts of the satellite shall be fabricated. In the Testing phase, most of the fabricated components shall be tested in ground using available test facilities. The Hardware-In-Loop testing facility (On-Board-Computer In Loop Simulation OILS) is being setup to do extensive test and runs of the On Board Computer. There are some parts which can never be tested on ground, and we have to depend on Simulations for their validation. The testing of validation of the Sub-Systems will consume a lot of time and effort.

The objective of the Payload for Pratham is to measure the Total Electron Count in the Ionosphere. This is achieved by transmitting two linearly polarized beams of radio waves from the satellite and detecting the change in angle of polarization after they have crossed the ionosphere, using a ground station. Obviously, by this method, we will me able to measure the TEC of the region only directly above the ground station. Since more the number of ground stations, more TEC data can be produced; team members are approaching other universities to set up ground stations for Pratham. They will educate the students from these universities about our Satellite project and enthuse them towards similar endeavors. This is a small step in trying to give back to the society from which we have got so much.

The list of models of the Satellite that need to be made as the project matures include Lab Model, Engineering Model, Qualification Model, Flight Model and Spare Model. But since Pratham is a Student Satellite, the concept of Proto-Flight Model will be used. Hence the model that successfully passes the Qualification Tests will be lunched directly.

We wish to launch of Pratham in the launch scheduled in the 4th quarter of 2009, which is a 10:30 polar sun-synchronous orbit. Since it is a small satellite, it will be carried as a piggy-back on this PSLV launch. For the launch vehicle interface, we will be using IBL230V2 which will be provided by VSSC.

The first stage of success is when the Flight Model is made. We can say that the educational goals and the Design, Analysis, etc. goals for the satellite have been met at this point. Hence the importance attached to this phase is 55%, which is a summation of the importance attached to these two aspects in the Mission Statement. Hence even if there is a failure during launch, mostly because of factors which are not in our control, your mission will be a partial success.

Each of the Stages of the Satellites Success Criterion has been given importance as deemed fit by the Team. In the end, when the Satellite works successfully for its mission life of 4 months in space, the project will become a complete success (100%). The mission life is 4 months because we will need 2 months of data to validate it against known standards, and then we wish to acquire 2 months of additional data that we can claim is our own and correct. The design life of the Satellite is 1 year.

2.3 Continuity

For a student project, continuity of the project is the biggest problem. Continuity can be hampered when the students who have held important posts within the team pass-out from the institute. They work has to be carried forward by others in the team; hence they have to be trained to handle additional responsibilities. To ensure continuity, many steps are taken within the team.

Every year, around September, a selection test is taken which is open to all the students of the institute. The selection test consists of a quiz to screen the candidates. Then the candidates have to give a presentation on a topic that is given to them. After successfully clearing the selection tests, the candidate is inducted into the team as an informal member. After working on the team for 2-3 months, he is given formal membership if the team is satisfied with his work. In this manner, new batch of students is inculcated every year to replace the old out-going batch. Since the old out-going batch leaves around April, it gives the new batch about 7 months to learn about the Satellite from their seniors.

There is also a process setup to ensure continuity if the project drags too long due to some unforeseen circumstances. It is as follows:

On October 2009, a status report of Pratham Project shall be made. Realistic assessments of possibility of the Satellite to achieve 'launch readiness' by March 2010 shall be done. If it is possible, then the team shall go full steam and finish the Project by March 2010. If not possible, then a complete set of new Team Members shall be chosen/inducted into the team by November 09, called Batch2. Some date between Dec 2009 and Jan 2010 shall be chosen as the 'Stop Work on the Satellite Day'. Henceforth, the old Team (Batch 1) shall spend all the time till March 2010 in training the new Team (Batch2). On March 2010, the entire old Team (Batch 1) shall leave the Satellite Project handing it over to the new Team (Batch 2).

We hope the project doesn't come to this stage ever, but we have taken care of the worst case scenario also.

Chapter 3: System and Sub-System Requirements

A V-Model, as shown in Fig 3, was used to find the System and Sub-System Requirements.

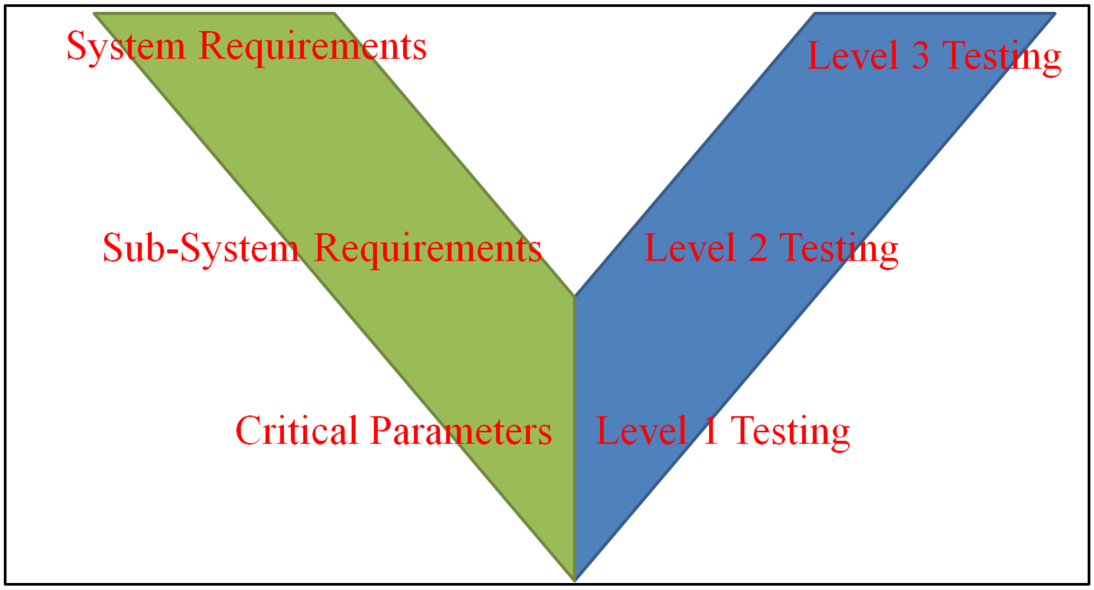


Figure 4: V Model

The Mission Statement and the Environment (space, launch vehicle, etc.) give rise to System Requirements. These System Requirements are handed down to the individual Sub-Systems. The Sub-Systems also interact with each other to give Sub-System Requirements. Finally from all these requirements come the Critical Parameters which the individual Sub-Systems have to design and satisfy. Similarly, the critical parameters are tested by the Sub-Systems in Level 1 testing. 2-3 Sub-Systems get together and do Level 2 testing where the interaction between these Sub-Systems is checked. The final Satellite level testing is done in Level 3 testing like vibration testing, etc.

3.1 System Requirements on the Sub-Systems

The System Requirements on the individual Sub-Systems is written below

Requirements on the Payload Sub-System from the System

- Payload Sub-System shall measure the Total Electron Count (TEC) of Ionosphere above IIT Bombay with 0.1 TEC units accuracy.

Requirements on the Communication and Ground Station Sub-System from the System

- Communication Sub-System shall transmit with the 1st monopole (Beacon) all over the world at a certain duty cycle (25%).
- They shall transmit data from the Satellite over India, using the 2nd monopole to the ground station at 1.2 kbps.
- They shall setup a ground station at IIT Bombay.
- They shall design low-cost (less than Rs10,000) ground stations for other universities.

Requirements on the Attitude Determination and Controls Sub-System from the System

- Attitude Determination and Controls Sub-System shall measure the attitude to 5^0 degrees accuracy along all axes.
- They shall measure the instantaneous position of the Satellite in orbit to 1 kilometers accuracy.

Requirements on the On Board Computer Sub-System from the System

- On Board Computer Sub-System shall carry out pre-launch checks of the Satellite before launch.
- They shall store the Health Monitoring Data onboard the Satellite when in orbit, as per the Data Budget[1]. The HM Data shall contain:
  - Time
  - Attitude data
  - Position data
  - Power sensors data

Requirements on the Power Sub-System from the System

- Power Sub-Systems shall recharge the batteries before launch using external charger.
- They shall detect the deployment of the Satellite into orbit using the deployment switch.
- They shall trap the solar power falling on the Satellite and store it in batteries. The Batteries have 5 Amp-hr capacity.

Requirements on the Structures Sub-System from the System

[1] The Data Budget is attached in the Section named on Budgets.

- Structures Sub-System shall make the Satellite frame such that it can withstand the launch loads.
- They shall make the Satellite frame such that it can withstand atleast 4 months of thermal loading cycles.

	FREQ. RANGE (Hz)	QUALIFICATION LEVEL	ACCEPTANCE LEVEL
LONGITUDINAL AXIS	5 - 10	10 mm (0 to peak)	8 mm (0 to peak)
	10 - 100	3.75 g	2.5 g
LATERAL AXIS	5 - 8	10 mm (0 to peak)	8 mm (0 to peak)
	8 - 100	2.25 g	1.5 g
SWEEP RATE		2 Oct/min	4 Oct/min

Table 15-2. Random Vibration Test Levels

Frequency (Hz)	QUALIFICATION	ACCEPTANCE
	PSD (g^2 / Hz)	PSD (g^2 / Hz)
20	0.002	0.001
110	0.002	0.001
250	0.034	0.015
1.000	0.034	0.015
2.000	0.009	0.004
g RMS	6.7	4.47
Duration	2 min/axis	1 min/axis

Figure 5: Sine and Random Vibration Launch Loads from PSLV C9 launch

Requirements on the Thermals Sub-System from the System

- none

Requirements on the Mechanism Sub-System from the System

- Mechanisms Sub-System shall make/use the Launch Vehicle Interface to be provided by VSSC and attach it to the main frame of the Satellite.
- They shall the Satellite is deployed into space by the launch vehicle using the Deployment Switch (SNAP circuit) which will switch on the Power circuit.

- The SNAP circuit should draw very low current (~10microA)
- The SNAP circuit should not trigger on due to the launch vibrations

Requirements on the Integration Sub-System from the System

- The Integration Team shall provide the following ports necessary for the pre-flight checks, charging the batteries and during deployment of the Satellite:
    - Access Port
    - Battery Charger
    - Kill Switch (RBF Pin)

Requirements on the Quality Sub-System from the System

- Quality Team shall make sure that the Satellite is made as per the Quality standards deemed necessary by ISRO for the success of the project.[2]
- They shall lay down rules, handling procedures, test procedures, etc. to meet the Quality standards.
- They shall do the reliability analysis of the Satellite.
- They shall setup the 1lakh class Clean Room in IIT Bombay for Pratham.

3.2 Requirements on one Sub-System from another Sub-System

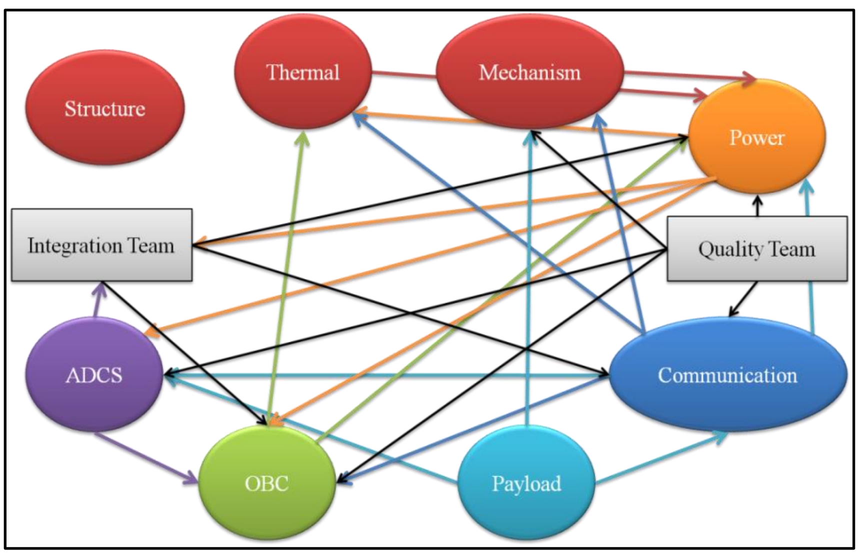


Figure 6: Sub-System to Sub-System Requirements

[2] This requirement is very vague because it is covered in detail in the Quality Sub-System Report. All the Quality specifications applicable to TWSAT Mini-Satellite will be applicable to Pratham.

Requirements from Payload Sub-System to Communication and Ground Station Sub-System

- Communication Sub-System shall maintain the polarization purity of both the monopoles better than 30 dB, i.e. an axial ratio of 1000:1.
- They shall maintain an accuracy of 0.3dB in signal strength ratio measurement at the ground station.
- They shall detect the difference is the polarization angle between the two signals at the ground station with an accuracy of 1 degrees.

Requirements from Communication and Ground Station Sub-System to Power Sub-System

- Power Sub-System must supply the 1st monopole (Beacon) with 1.5W when it is switched on.
- Power Sub-System must supply the 2nd monopole with 4W when it is switched on.
- The peak power when both the monopoles are switched on is 5.5W.
- Due to the operational sequence, the average power needed by both the monopoles over one day is 0.58W.

Requirements from Communication and Ground Station Sub-System to Mechanism Sub-System

- Mechanisms Sub-System shall deploy the 2 monopoles such that they make 90 degrees angle with the side plane. The ± error is TBD.
- They shall maintain the distance between the 2 monopoles greater than 15cm.

Requirements from Payload Sub-System to Mechanism Sub-System

- Mechanism Sub-System shall maintain the parallelism between the monopoles as stated below. When two tips of the two monopoles are overlapped, the other tip of the 2nd monopole must lie within the cone; with a base radius of 0.3cm and the 1st monopole as its central axis.

Requirements from Communication and Ground Station Sub-System to Attitude Determination and Controls Sub-System

- Attitude Determination and Controls Sub-System shall maintain the Satellite at 0^0 pitch and 0^0 roll along the orbit reference frame, with a maximum error of ±10 deg in both these axes.

Requirements from Attitude Determination and Controls Sub-System to On Board Computer Sub-System

- OBC Sub-System shall execute the Control Law as per the operational sequence.
- They shall interface with the following sensors:
    - Magnetometer (UART)
    - GPS (UART)
    - 12 Sun-Sensors (1 ADC with multiplexer)
- They shall drive the 3 magnetorquers using PWM.

Requirements from Attitude Determination and Controls Sub-System to Integration Sub-System

- Integration Team shall make the principal axis of the Satellite coincide with the geometric axis.
- They shall make the Satellite meet the conditions for Static stability, namely
    - $I_x > I_y > I_z$
    - $I_x < I_y + I_z$
- They shall place the 3 magnetorquers on 3 sides along the 3 body axis, namely the zenith, the leading velocity and the sun-side.
- They shall place the GPS on zenith and expose the antenna to space.
- They shall place the magnetometer at the position with least magnetic disturbances.
- They shall place the 12 Sun-Sensors along the 12 edges such that their field of view is not curtailed.

Requirements from Communication and Ground Station Sub-System to On Board Computer Sub-System

- OBC Sub-System shall send packets of data at 1.2kbps with AX25 communication protocol when Satellite is in mode 3, as per operational sequence.

Requirements from On Board Computer Sub-System to Power Sub-System

- Power Sub-System shall supply continuous power of 1W to the OBC Sub-System.
- OBC Sub-System shall update Power Sub-System every two second, with the list of components that should be on and the rest are to be switched off.
- Power Sub-System shall send HM data of its sensors when the OBC polls for data.

Requirements from Power Sub-System to On Board Computer Sub-System

- Power Sub-System shall give a hard interrupt of highest priority if the power drops below a certain threshold. Then OBC shall get ready to be shut down within the next 1-5 seconds. (TBD)
- Power Sub-System shall inform OBC Sub-System if some component 'misbehaves'[3] and had to be shutdown. The decision to shut it down shall be taken locally at Power Sub-System.
- The Power Sub-System shall attempt to revive the 'misbehaving' component by restarting it.

Requirements from Power Sub-System to Integration Sub-System

- Integration Team shall place solar panels on the 4 sides, namely sun-side, zenith, velocity-leading side and velocity-lagging side.
- Integration Team shall make sure that shadows due to other deployed parts shall not fall on the solar panels.

Requirements from Payload Sub-System to Attitude Determination and Controls Sub-System

- Attitude Determination and Controls Sub-System shall maintain the Satellite at 0^0 yaw along the orbit reference frame, with a maximum error of ±10 deg in this axes.

Requirements from Power Sub-System to Attitude Determination and Controls Sub-System

- During Mode 2, Attitude Determination and Controls Sub-System shall try to achieve an attitude such that maximum solar irradiation falls on the solar panels.

Requirements from Power Sub-System to Thermals Sub-System

- Thermals Sub-System shall protect the solar panels from heating above 70^0C.
- They shall maintain the temperature range of the battery within 0^0 to 30^0C.
- They shall remove the excessive heat from Power Circuits, since the temperature range of the components (industrial grade) is -40^0 to $+85^0$ C.

Requirements from Communication and Ground Station Sub-System to Thermals Sub-System

- Thermals Sub-System shall protect the monopoles from heating above 100^0C.

[3] Misbehaving refers to drawing too much current and hence detected by the current limiting switches on the Power circuit. There is no provision to judge the performance of the components.

- They shall remove the excessive heat from the 2 Monopole circuits, since the temperature range of the components (industrial grade) is -40^0 to +85^0 C.

Requirements from On Board Computer Sub-System to Thermals Sub-System

- They shall remove the excessive heat from OBC Circuits, since the temperature range of the components (industrial grade) is -40^0 to +85^0 C.

Requirements from Mechanism Sub-System to Power Sub-System

- Power Sub-System shall supply power to the Monopole Deployment circuit. (approx 3W for few sec, TBD)
- They shall provide power to the single-fail-redundancy system for the Monopole Deployment Mechanism, using a different line.

Requirements from Thermals Sub-System to Power Sub-System

- Power Sub-System shall supply power to the Battery Heater Circuit. (values TBD)

Requirements from Integration Sub-System to On Board Computer Sub-System

- The final circuit board should have a natural frequency above 120Hz.
- The size of the circuit board should be 12cm X 12cm. The harness for the circuit is shown below.
    - 1cm border shall be left on all sides along with a central square of 1cm, and it must be grounded. (green region)
    - The red region is 0.7cm from the circuit bottom, and tall components should not be mounted there.

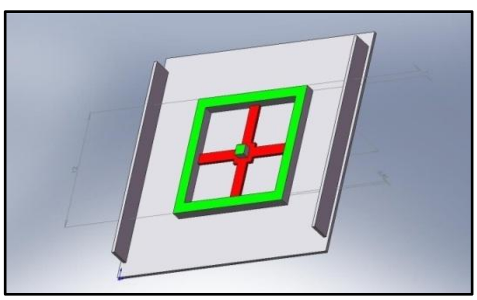


Figure 7: Harness for OBC Circuit

Requirements from Quality Sub-System to On Board Computer Sub-System

- Hardware Quality

- Extensive testing[4] before launch to prevent Infant Mortality.
- Satellite is designed for a life of 1 year; hence probability of failure should be below a certain threshold. (TBD)
- Soldering and Circuit Design guidelines given by ISRO, will be followed

- Software quality[5]: TBD

Requirements from Integration Sub-System to Power Sub-System

- The final circuit board should have a natural frequency above 120Hz.

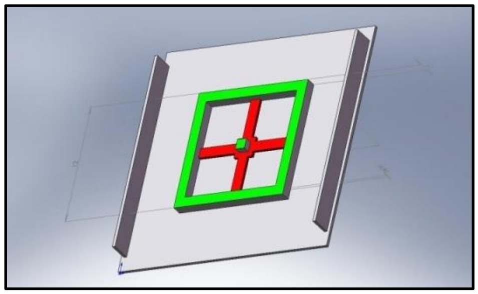


Figure 8: Harness for Power Circuit

- The size of the circuit board should be 12cm X 12cm. The harness for the circuit is shown below.
    - 1cm border shall be left on all sides along with a central square of 1cm, and it must be grounded. (green region)
    - The red region is 0.7cm from the circuit bottom, and tall components should not be mounted there.

Requirements from Quality Sub-System to Power Sub-System

- Hardware Quality
    - Extensive testing before launch to prevent Infant Mortality.
    - Satellite is designed for a life of 1 year; hence probability of failure should be below a certain threshold. (TBD)
    - Soldering and Circuit Design guidelines given by ISRO, will be followed
- Software quality: TBD

Requirements from Quality Sub-System to Communication and Ground Station Sub-System

- Hardware Quality

[4] ~320hrs for commercial ISRO Satellites
[5] We don't think we will need formal verification of the code.

- Extensive testing before launch to prevent Infant Mortality.
- Satellite is designed for a life of 1 year; hence probability of failure should be below a certain threshold. (TBD)
- Soldering and Circuit Design guidelines given by ISRO, will be followed

Requirements from Integration Sub-System to Communication and Ground Station Sub-System

- The final circuit board should have a natural frequency above 120Hz.
- The size of the 2 circuit boards should be 8cm X 8cm. The two harnesses for the 2 circuits on the same side (anti-sun side) are shown below.
    - 1cm border shall be left on all sides along with a central square of 1cm, and it must be grounded. (green region)
    - The red region is 0.7cm from the circuit bottom, and tall components should not be mounted there.

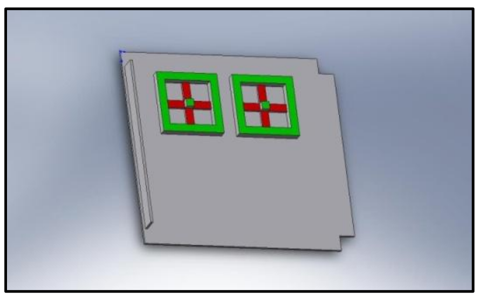


Figure 9: Harness for Communication Circuit

Requirements from Quality Sub-System to Attitude Determination and Control Sub-System

- Hardware Quality
    - Extensive testing before launch to prevent Infant Mortality.
    - Satellite is designed for a life of 1 year; hence probability of failure should be below a certain threshold. (TBD)
    - Soldering and Circuit Design guidelines given by ISRO, will be followed

Requirements from Quality Sub-System to Mechanism Sub-System

- The reliability of the monopole deployment mechanism and the SNAP circuit should be ~1. Hence the hardware needs to be tested a large number of times (~500 times).

Chapter 4: Configuration Layout and Integration Sequence

Configuration Layout is the position of the different components on the different sides of the Satellite. The different sides of the Satellite are named as:

- sun side (always faces the sun)
- antisun side (never faces the sun)
- zenith side (along the radius vector from center of earth, pointing away from earth)
- nadir side (along the radius vector from center of earth, pointing towards earth)
- leading side (along the direction of velocity)
- lagging side (opposite to the direction velocity)

4.1 Configuration Layout

Most of the constraints on the Integration Team are on the configuration layout. (Refer to System and Sub-System Requirements section.) Some of the other constraints are as follows:

- During integration, one pre-chosen side will be attached last. There should be very few connections on this side. Hence the lagging side is chosen to be this side.
- The magnetometer should be kept farthest away from all the other electrical circuits, to reduce magnetic interference. Hence it will be placed in the lagging side.
- The battery will be placed on the nadir side so that better thermal control can be done and the moment of inertia constraints will also be met.
- Since the wires from the Sun-Sensors will be carrying analog signals, the wire length should be kept as less as possible.
- Since the wires going to the magnetorquers will be carrying analog signals in the form of current, the wire length should be kept as less as possible.
- The OBC circuit is placed on the leading side since it will be close to all the 3 magnetorquers, the Power circuit and the Monopole2 circuit. It will be far away from the Magnetometer.
- The Power circuit is placed on the sun side since it will be close to all the 4 solar panels on the zenith, sun, leading and lagging sides; the OBC circuit, the battery and the SNAP circuit. It will be away from the Beacon, Monopole 2 circuits and monopole deployment mechanism.

- The Monopole Deployment mechanism is placed on the Anti-Sun side so that the shadow from the monopoles doesn't fall on the Solar Panels.

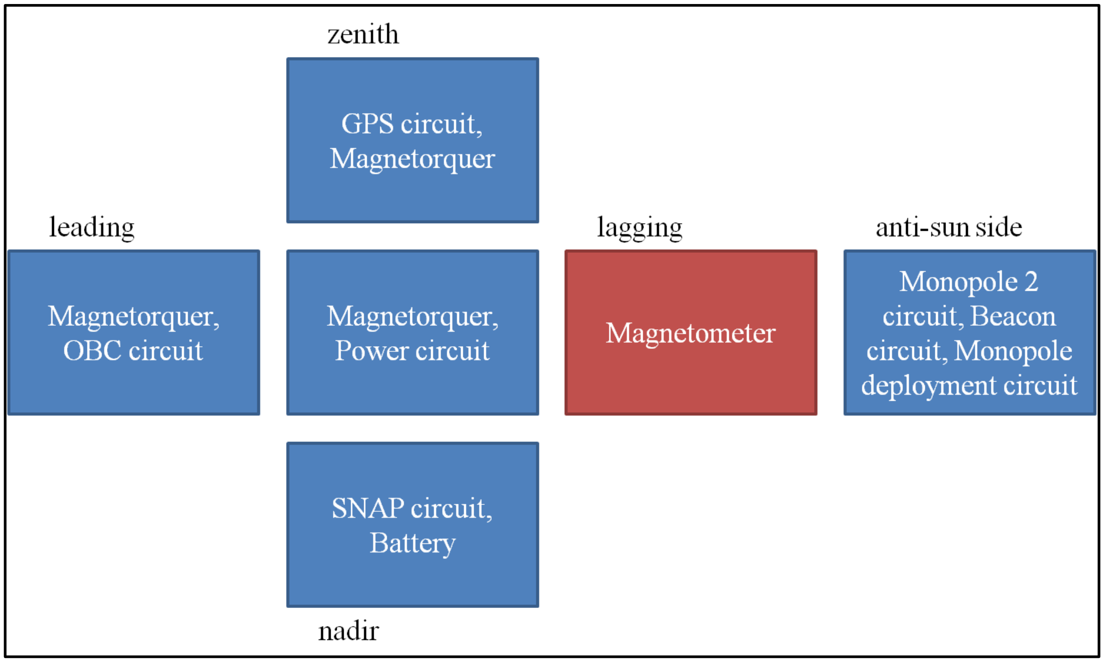


Figure 10: Internal Configuration Layout

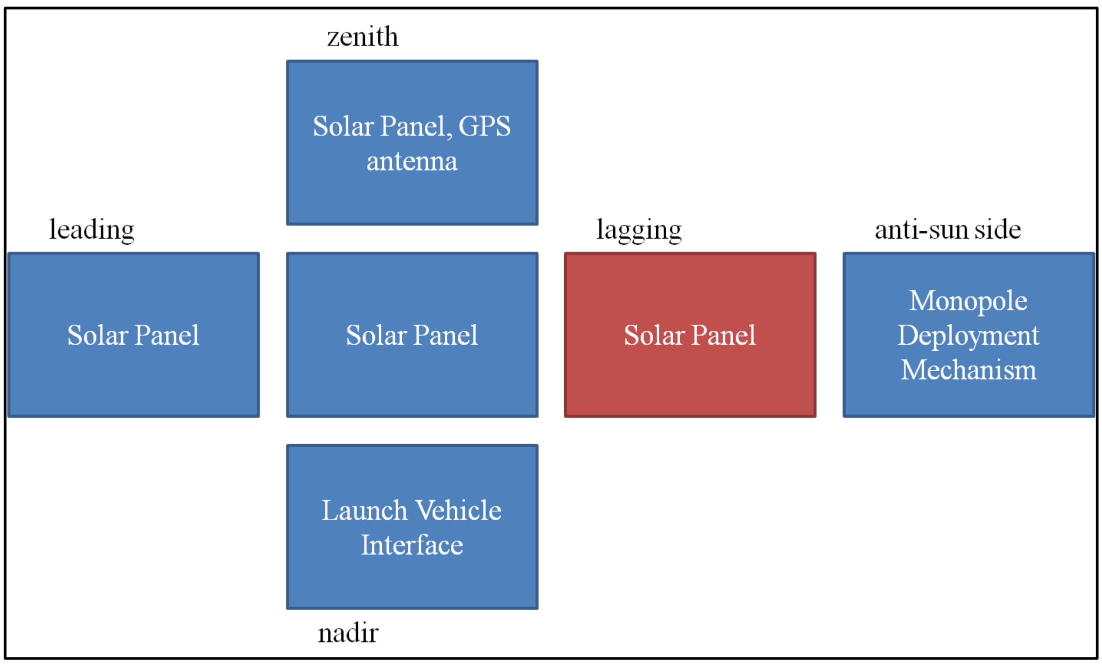


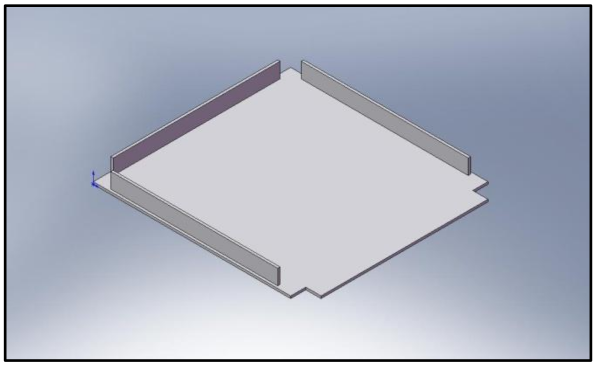
Figure 11: External Configuration Layout

All the constraints are satisfied by the configuration layout shown above for inside and outside the Satellite. The side marked in red (lagging side) is the last side to be integrated.

4.2 Integration Sequence

Step 1: Nadir Side Integrated with the LVI

The nadir side does not have any circuits. The 4 sunsensors mountings on the outside surface are marked in darkblue.



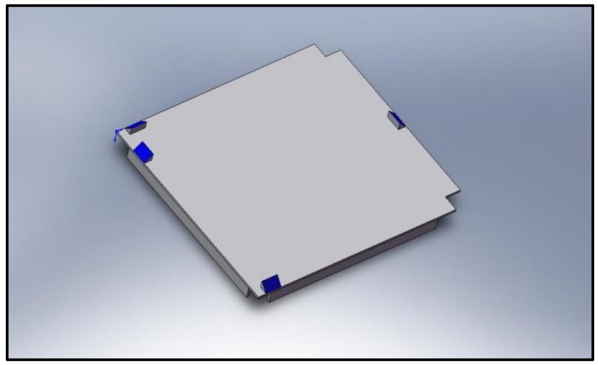


Figure 12: Nadir Side

The Launch Vehicle Interface is IBL230V2. It will be provided to us by VSSC. The Integration of the LVI with the Nadir surface will be done by the Mechanism Sub-System.

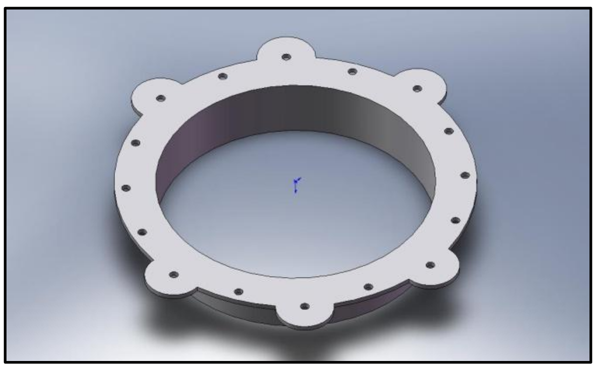


Figure 13: Launch Vehicle Interface (IBL230V2)

Step 2: Nadir + LVI Integrated with the Sun side

The Sun side has the solar panels on the exterior and the magnetorquer and Power circuit in the interior.

Step 3: Nadir + LVI + Sunside Integrated with the Antisun side

The Antisunside has the monopole deployment mechanism on the outer surface. In the inner surface, there is are the 2 circuits (Beacon and Monopole 2 circuit).

Step 4: Nadir + LVI + Sunside + Antisunside Integrated with the Leading side

The Leading side has the solar panels on the exterior and the magnetorquer and OBC circuit in the interior. The reason for integration this side before the zenith is that, if the zenith is ttached then attaching the Leading side would become very difficult.

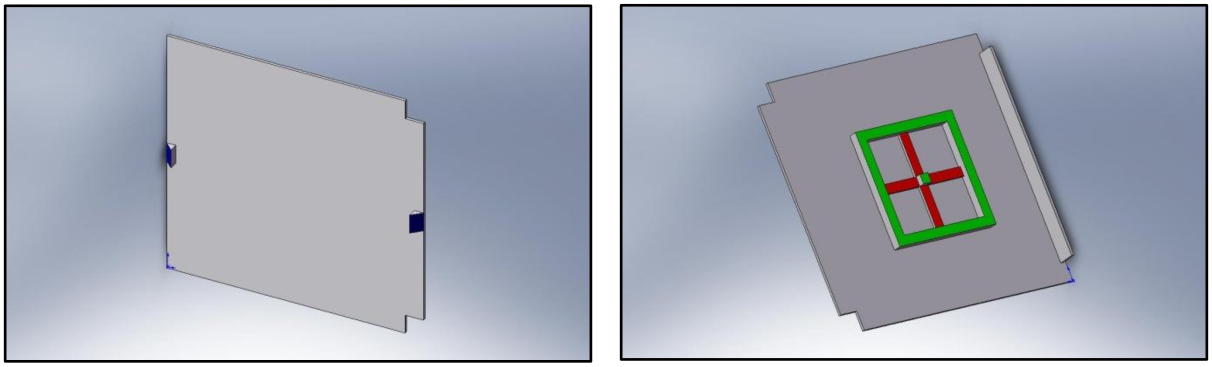


Figure 14: Sun Side

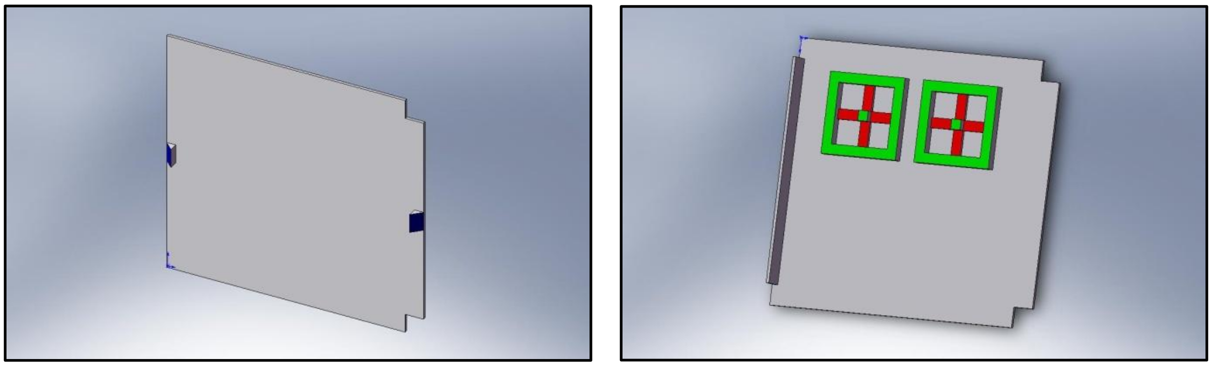


Figure 15: Antisun Side

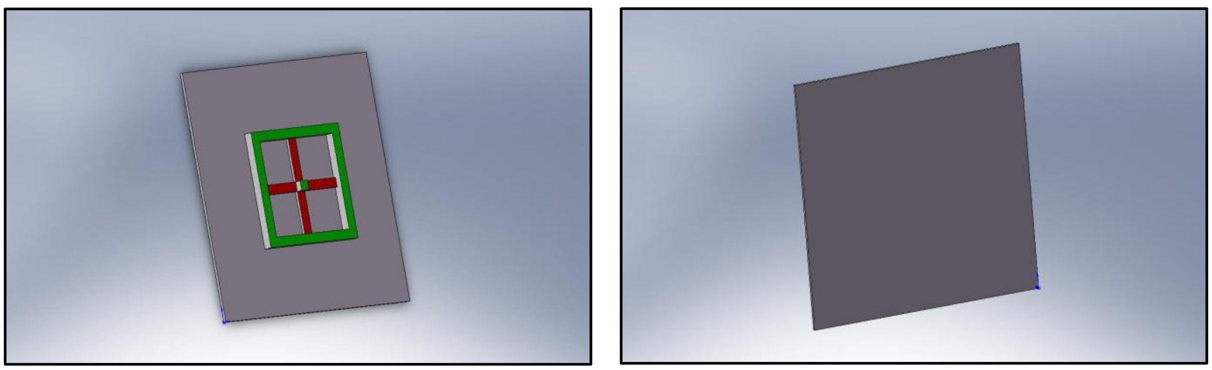


Figure 16: Leading Side

Step 5: Nadir + LVI + Sunside + Antisunside + Leading Integrated with the Zenith side

The Zenith side has the GPS antenna and the Solar Panels on the exterior. In the inside, it houses the magnetorquer and the GPS circuit.

Step 6: Nadir + LVI + Sunside + Antisunside + Leading + Zenith Integrated with the Lagging side

The lagging side is the sixth side which is integrated in the end. Hence the flanges to be used for integration is outward and can be tightened from outside. It houses the magnetometer on the inside and the solar panel on the outside. Thus the Satellite is completely integrated.

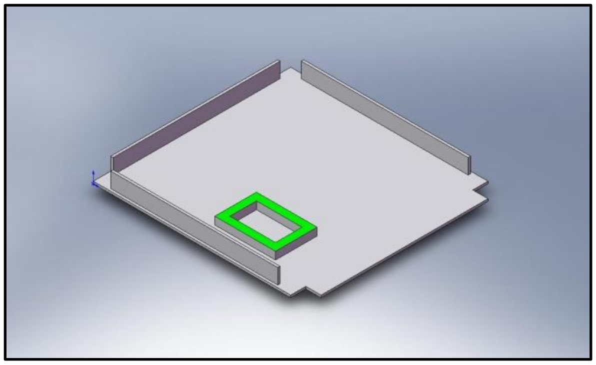
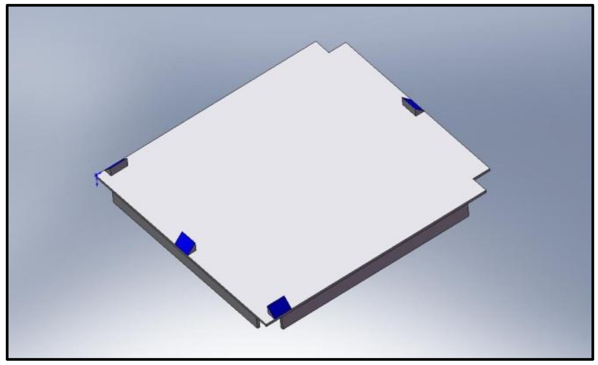



Figure 17: Zenith Side

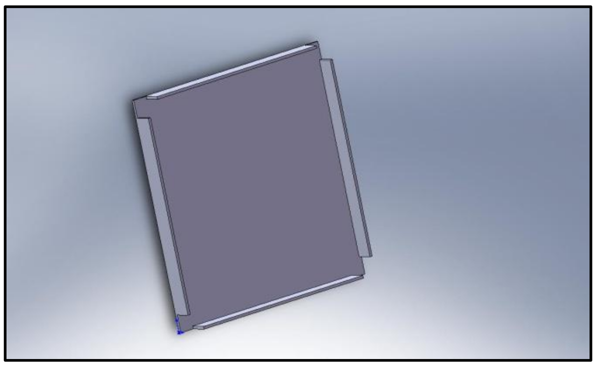
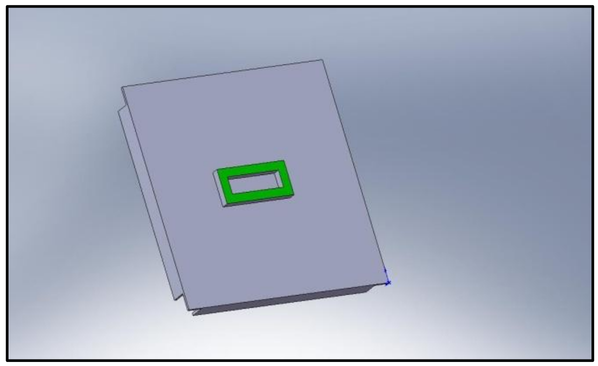



Figure 18: Lagging Side

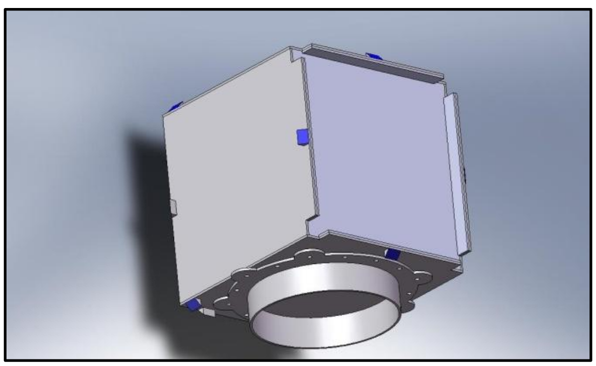
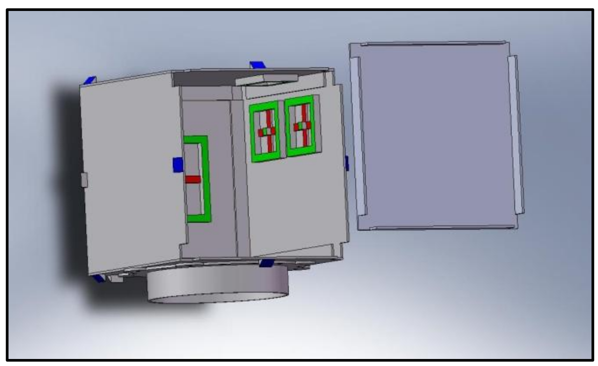



Figure 19: Final Integrated Satellite

Chapter 5: Operational Sequence

The Satellite passes through various stages of operation (modes). This chapter lists the tasks that the Satellite should do in each of these modes.

5.1 Modes of Operation of the Satellite

The different modes of operation of the Satellite are listed below. The flowchart describes the transfer from one mode to another.

Mode -1: Pre-flight checks

Mode 0: Liftoff

Mode 1: Detumbling

Mode 2: Nominal operation without Downlink

Mode 3: Nominal operation with Downlink

Mode 4: Emergency Mode

Mode 5: Safe Mode

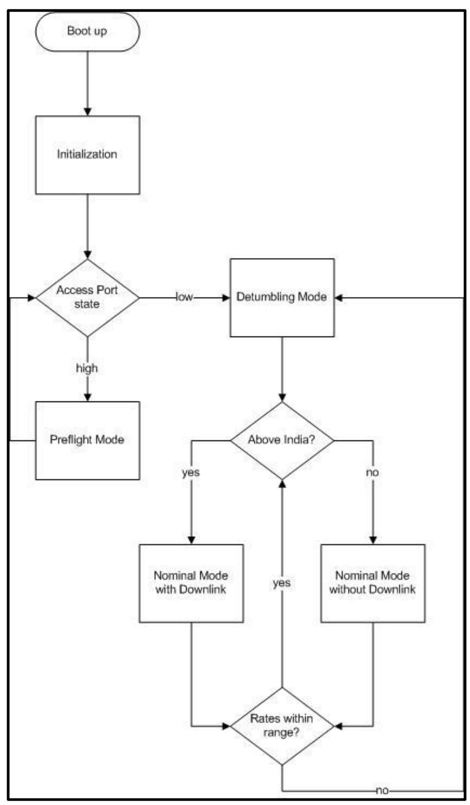


Figure 20: Flowchart for the Modes of Operation

Mode -1: Pre-flight checks

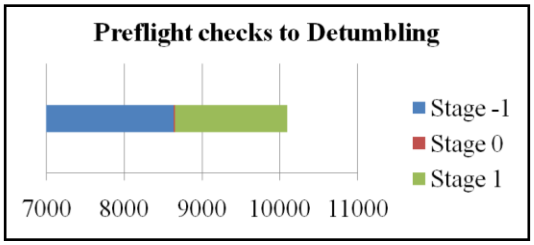
- Satellite shall be inside the Clean Room at the launch site.
- The access ports shall be used to check the Satellite's health.
- The batteries shall be charged to full capacity.
- The Satellite is ready for launch and mounted on the Launch Vehicle.
- Before launch, the RBF pin shall be removed from Power circuit.
- This mode starts about 6 days before launch. (T – 6 days)
- In the event of a delay, the batteries shall be recharged after 30 days on the launch vehicle.

Mode 0: Liftoff

- Satellite shall be inside the Launch Vehicle. This mode starts with liftoff and ends within 17-22 minutes after launch (T 0).
- All Sub-Systems shall be switched off.
- The Satellite shall be deployed into orbit by the Launch Vehicle, using the Launch Vehicle Interface.
- The SNAP circuit (Deployment Switch) shall detect the Satellite is deployed.

Mode 1: Detumbling

- The SNAP circuit shall switch on the Power circuit.
- The Power circuit shall switch on the other components in the following order.
    - OBC circuit
    - Beacon circuit
    - All control sensors and magnetorquer
    - Monopole 2
- All processors, memory units, sensors and actuators shall be initialized by the OBC.
- Health Monitoring checks shall be done for all the components by the OBC.
- The 2 Monopoles shall be deployed, before detumbling begins.
- When Satellite is deployed it has rotational rate about 5deg/sec on all 3 axis, this shall have to be reduced to 0.1deg/sec for nominal mode operation. This process is called Detumbling. It takes about 2-6 orbits, or a maximum of 9 hours to detumble completely.

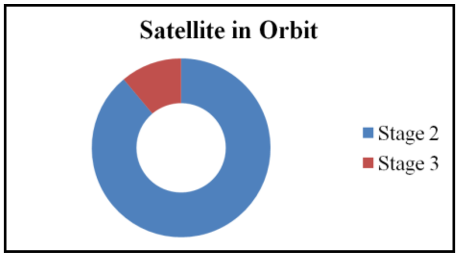


Mode 2: Nominal operation without Downlink

- This shall be the normal mode of operation of the Satellite in orbit but when not over India.
- Beacon shall be switched on. It will on a 25% duty cycle.
- The Monopole 2 shall be switched off.
- The Satellite attitude shall be oriented such that maximum power will be received by the Solar Panels.
- Health Monitoring data as per the Data Budget, shall be stored by the OBC.

Mode 3: Nominal operation with Downlink

- This shall be the normal mode of operation of the Satellite in orbit when it is over India.
- Beacon shall be switched on at 100% duty cycle.
- The Monopole 2 shall be switched on such that:
    - When Satellite will be over India but not over IITB, Mon2 will transmit the instantaneous position and attitude data.
    - When Satellite will be over IITB, Mon2 will transmit the 64kB of stored data in memory; corresponding to the HM for the previous 24 hrs.



Mode 4: Emergency Mode

- This mode shall be entered when some error is encountered in any component, sensor or application, during its operation.
- The error states and their corresponding error correction algorithms have been identified:

- The errors in red cannot be corrected onboard.
- The errors in blue can be corrected onboard.
- The component that is responsible for executing the correction algorithm is also specified below.

Table 2: Errors and their possible corrections

Name	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10	E 11	E 12	E 13	E 14
Beacon	X													
Monopole2		X												
Monopole Deployment Mechanism			X											
Solar Panels				X										
Power Circuit				Run for some time on the battery before Satellite dies. Satellite will enter "Safe mode". Components start getting switched off one by one.	X	Directly route the power from solar panels. Satellite alive only when in sun-light. Satellite will enter "Safe mode". Components start getting switched off one by one.								
Battery						X								
OBC citcuit							X	Orbit estimator will run in the OBC.						
GPS								X						
Mangetometer									X					
Magnetorque										X				

r														
Sun Sensor											X			
Launch Vehicle Interface												X		
Access Ports													X	
Main Body														X

Mode 5: Safe Mode

- This mode shall be entered when the power drops below a threshold.
- The components will be switched off in the following manner, by the Power circuit:
    - monopole 2
    - All control sensors and magnetorquer
    - OBC circuit
    - Beacon
    - Power circuit

Chapter 6: Wires and Connectors

6.1 Connections on the Satellite

The connectivity diagram for the Satellite is as shown below. The main nodes are the OBC and The Power circuit boards. The colour coding stands for the different Sub-Systems who are responsible for the components. (Green – OBC, Yellow – Power, Purple – Controls, Blue – Communication, Red – Integration, Thermals, others)

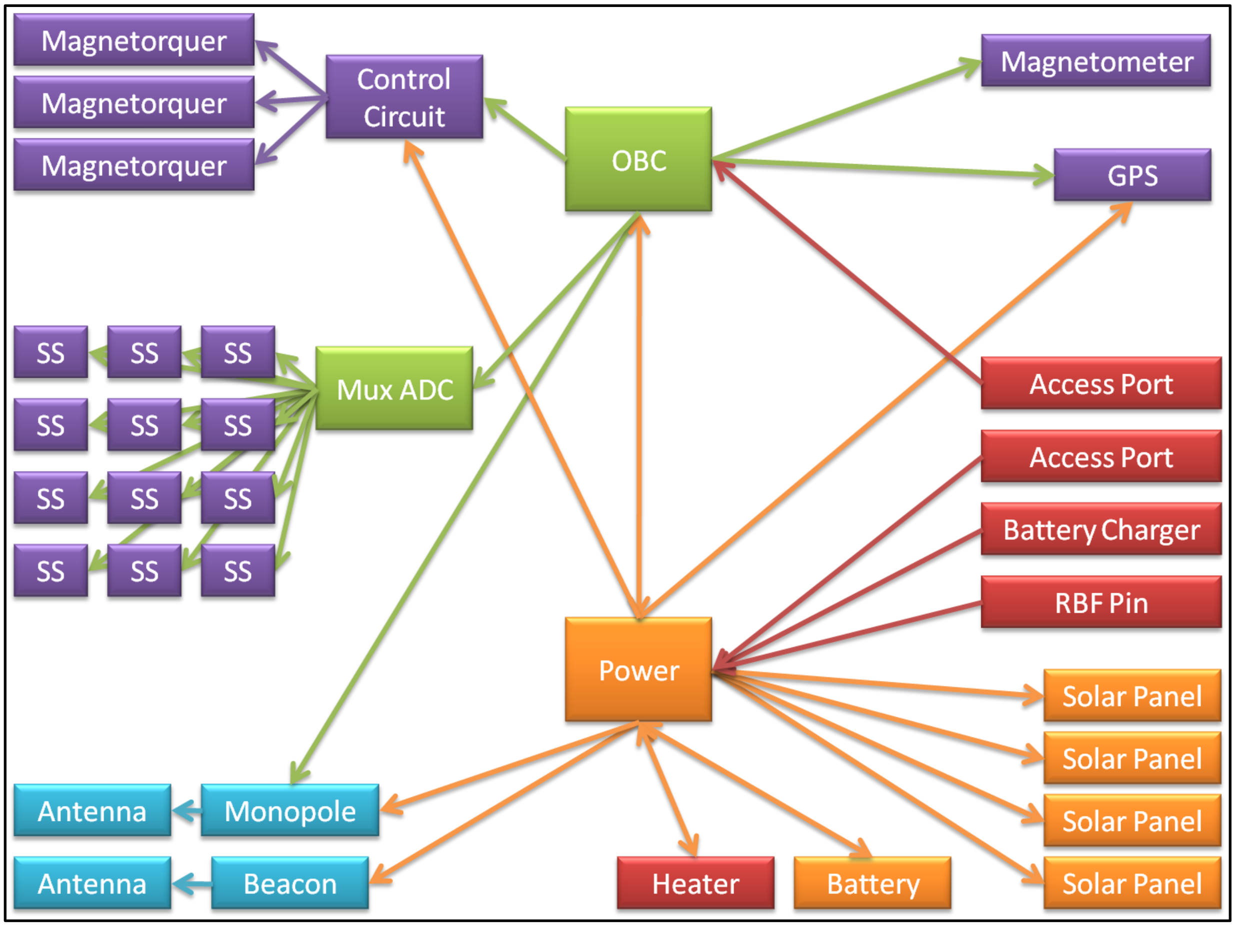


Figure 21: Connectivity Diagram

A detailed list of all the connections on the Satellite is shown below.

Table 3: List of connections

Start	End	Number of pins
Beacon Circuit	Antenna	2; 1 signal surrounded with GND

Beacon Circuit	Power Circuit	2; 5Volts, 3 Watts
Monopole 2 Circuit	Antenna	2; 1 signal surrounded with GND
Monopole 2 Circuit	Power Circuit	2; 5Volts, 3 Watts
Monopole 2 Circuit	OBC circuit	6; 2-Signal in AX25 protocol, 4-SPI
Monopole Deployment Mechanism	Power Circuit	5; 2X(5Volts, 3 Watts) + check that it is deployed
Solar Panels on Sun Facing side	Power Circuit	2
Solar Panels on Zenith side	Power Circuit	2
Solar Panels on Leading velocity side	Power Circuit	2
Solar Panels on Lagging velocity side	Power Circuit	2
Power circuit	OBC circuit	4; 2 Power, 2 data I2C
Battery	Power Circuit	5
Battery	Heater Circuit	2
GPS	Power Circuit	2; 5Volts, 400mA current, 2 Watts
GPS	OBC circuit	4; serial port, RS232, dual berg
Magnetometer	OBC circuit	6; serial port

OBC circuit (Control Circuit on OBC)	Power Circuit	2; 3.3Volts, 9 Watts
Magnetorquer on sun facing side	OBC circuit (Control Circuit on OBC)	2
Magnetorquer on leading velocity side	OBC circuit (Control Circuit on OBC)	2
Magnetorquer on nadir side	OBC circuit (Control Circuit on OBC)	2
Sun sensor (total 12 sun-sesnors)	OBC circuit	2 (X 12); 2 for each SS
Access Ports	Power Circuit	2; for battery charging
External Battery charger port	Power Circuit	2
Access Ports	OBC circuit	4; SPI

6.2 Connectors

Connectors provide a sturdy interface for wires (coming into / going out of) a board. They keep the routing of wires simple to track.

Using separate connectors for power supply and data, keeps high current carrying wires away from other wires. So they do not interfere in other low current carrying wires. But they takes up lot of space. Using integrated power and data connectors, reduces confusion in routing of wires. But it keeps high current carrying in proximity of the other wires.

We have decided to use a combination of both the methods. Because

1. PRATHAM is not facing space constraints.
2. Power carrying wires in PRATHAM do not carry significant current to affect other wires.

3. First method applies to those boards where wires come from sensors scattered all over the satellite.
4. Second method applies between those boards that supply power as well as data. Namely OBC and Power.

Some of the additional features that we looked for in the connectors are:

1. SMT – Surface Mount Type
2. Connector screwed to board
3. Screwed connection between mates
4. Horizontal type
5. Wires crimped to connectors
6. DIL (Double In Line) for Data connectors with even number of pins.
7. TIL (Triple In Line) for Data connectors with pins in multiple of three.

Presently we have kept Extra pins i.e Unassigned pins so as to have room for any future change of requirements.

Given below is the list of connectors with their photographs that are to be used on Pratham.

Connectors on the Power board

Figure 22: Male - M80-5000000M5-04-333-00-000 (Harwin)

Figure 23 Female - M80-4000000F1-04-325-00-000 (Harwin)

1. Solar panel to Power Board (2 such will be req.)
   i. Male - M80-5000000M5-04-333-00-000 (Harwin)
   ii. Female - M80-4000000F1-04-325-00-000 (Harwin)
2. Monopole 2 ckt. + GPS

3. Power to Control Ckt. + Beacon
4. Monopole deployment

Connectors on OBC Board

Figure 24: Male - M80-5L104M5-02-333

Figure 25: Female - M80-4D104F1-02-326

OBC to power (on power as well as OBC)

1. Male - M80-5L104M5-02-333
2. Female - M80-4D104F1-02-326

Figure 26: Male - M80-5L12405M1-02-333-00-000

Figure 27: Female - M80-4C12405F1-02-327-00-000

All sun sensors to OBC

1. Male - M80-5L12405M1-02-333-00-000
2. Female - M80-4C12405F1-02-327-00-000

Monopole circuit to the Antenna

2. TNC Straight Crimp Type plug - Solder of crimp contact - 3 piece, Cambridge Products; cpmctnc13.pdf
3. RG 142 A/U,AWG#18,Diameter 0.195", weight 74 gms/m, losses 0.3dB/m, Covered with FEP,Double shielded with 2 silver coated copper braids,Central Conductor is solid copper; lcom_025-06_RG142_and_RG213_50_Ohm_Cable_Assemblies.pdf

Connectors on Other Sub-System Boards

Figure 28: Male - M80-4C10205F1-02-325-00-000

Figure 29: Female - M80-4C10205F1-02-325-00-000

Monopole 2 ckt

1. Male - M80-4C10205F1-02-325-00-000
2. Female - M80-4C10205F1-02-325-00-000

Figure 30: Male - M80-5L10822M7-02-333-00-000

Figure 31: Female - M80-4C10805F1-02-325-00-000

Control circuit

1. Male - M80-5L10822M7-02-333-00-000
2. Female - M80-4C10805F1-02-325-00-000

The comprehensive list of all the connectors and wires entered together in the table is shown below. The entire list is not complete as more work in this direction will be done during DDR.

Table 4: Connectors and Wires

Start	**End**	**Number of pins**	**Connector at start**	**Connector at end**	**Wire**	**length**
Beacon Circuit	Antenna	2; 1 signal surrounded with GND	SMA Precision, Cannon 50ohm connectors, ITT; RF50-SMAprecision.pdf	TNC Straight Crimp Type plug - Solder of crimp contact - 3 piece, Cambridge Products; cpmctnc13.pdf	RG 142 A/U,AWG#18,Diameter 0.195", weight 74 gms/m, losses 0.3dB/m, Covered with FEP,Double shielded with 2 silver coated copper braids,Central Conductor is solid copper; lcom_025-06_RG142_and_RG213_50_Ohm_Cable_Assemblies.pdf	
Beacon Circuit	Power Circuit	2; 5Volts, 3 Watts	2 power lines	[**3rd** connector] Male - M80-5000000M5-04-333-00-000 (Harwin), Female - M80-4000000F1-04-325-00-000 (Harwin)		
Monopole 2 Circuit	Antenna	2; 1 signal surrounded with GND	SMA Precision, Cannon 50ohm connectors, ITT; RF50-SMAprecision.pdf	TNC Straight Crimp Type plug - Solder of crimp contact - 3 piece, Cambridge	RG 142 A/U,AWG#18,Diameter 0.195", weight 74 gms/m, losses 0.3dB/m, Covered with FEP,Double shielded with 2 silver coated copper braids,Central Conductor is solid copper; lcom_025-06_RG142_and_RG213_50_Ohm_Cable_Assemblies.pdf	

				Products; cpmctnc13.pdf		
Monopole 2 Circuit	Power Circuit	2; 5Volts, 3 Watts	[**1st** connector] Male - M80-4C10205F1-02-325-00-000 (Harwin), Female - M80-4C10205F1-02-325-00-000 (Harwin)	[**3rd** connector] Male - M80-5000000M5-04-333-00-000 (Harwin), Female - M80-4000000F1-04-325-00-000 (Harwin)		
Monopole 2 Circuit	OBC circuit	6; 2-Signal in AX25 protocol, 4-SPI	[**1st** connector] Male - M80-4C10205F1-02-325-00-000 (Harwin), Female - M80-4C10205F1-02-325-00-000 (Harwin)			
Monopole Deployment Mechanism	Power Circuit	5; 2X(5Volts, 3 Watts) + check that it is deployed	NA	NA		
Solar Panels on Sun Facing side	Power Circuit	2		[**1st** connector] Male - M80-5000000M5-04-333-00-000		

				(Harwin), Female - M80-4000000F 1-04-325-00-000 (Harwin)		
Solar Panels on Zenith side	Power Circuit	2		[**2nd** connector] Male - M80-5000000 M5-04-333-00-000 (Harwin), Female - M80-4000000F 1-04-325-00-000 (Harwin)		
Solar Panels on Leading velocity side	Power Circuit	2		[**1st** connector] Male - M80-5000000 M5-04-333-00-000 (Harwin), Female - M80-4000000F 1-04-325-00-000 (Harwin)		
Solar Panels on Lagging velocity side	Power Circuit	2		[**2nd** connector] Male - M80-5000000 M5-04-333-00-000 (Harwin), Female - M80-4000000F 1-04-325-		

				00-000 (Harwin)		
Power circuit	OBC circuit	4; 2 Power, 2 data I2C	Male - M80-5L104M5-02-333 (Harwin), Female - M80-4D104F1-02-326 (Harwin)	Male - M80-5L104M5-02-333 (Harwin), Female - M80-4D104F1-02-326 (Harwin)		
Battery	Power Circuit	5				
Battery	Heater Circuit	2				
GPS	Power Circuit	2; 5Volts, 400mA current, 2 Watts				
GPS	OBC circuit	4; serial port, RS232, dual berg				
Magnetometer	OBC circuit	6; serial port	serial port	6 data pins		
OBC circuit (Control Circuit on OBC)	Power Circuit	2; 3.3Volts, 9 Watts	2 power lines or 4 data + 4 power	2 power lines or 4 data + 4 power		
Magnetorquer on sun facing side	OBC circuit (Control Circuit on OBC)					

Magnetorquer on leading velocity side	OBC circuit (Control Circuit on OBC)	2				
Magnetorquer on nadir side	OBC circuit (Control Circuit on OBC)	2				
Sun sensor (total 12 sun-sesnors)	OBC circuit	2 (X 12); 2 for each SS		Male - M80-5L12405M1-02-333-00-000 (Harwin), Female - M80-4C12405F1-02-327-00-000		
Access Ports	Power Circuit	2; for battery charging				
External Battery charger port	Power Circuit	2				
Access Ports	OBC circuit	4; SPI				

Chapter 7: Mechanical Harness and Fasteners

The mechanical harnesses for the different circuits are shown in system requirements section. In this chapter, we will discuss the type of fasteners that will be used.

7.1 Rivets

Rivets are one of the most cost effective, easiest methods of joining general application attachments on the market today. Rivets are generally like those shown in the figure. They are cylindrical rods with one end protruding. The cylindrical thin portion is inserted through a hole made in any surface and any application and the other end is then flattened by hammering etc to fix the application to the surface.

Figure 32: Different types of rivets

The rivets assembly consists of two parts: the rivet body, called an "eyelet" and the mandrel or "nail" gripped by the jaws of the setting tool, the mandrel is drawn into the body of the rivet, which is expanded and drawn into a tight clinch against the back side (the blind side) of the work piece. When the assembly is tight enough, the mandrel breaks off at a predetermined tension and falls away.

Rivets cannot be used to join circuit boards in the satellite for mainly two reasons. The circuit boards are fragile. When the rivets are fitted the applications sustain a mild shock. The circuit boards won't be able to sustain such a shock. Also the circuit boards are attached to the inner sides of the satellite body. The riveting requires big riveting tools which will not be able to reach the circuit boards.

There are many advantages of riveting. The use of only a single, drilled or punched hole, filled effectively by an expandable rivet, offers a great increase in part design strength screw/bolt with nut designs. The nut designs require cutouts for the nut installation and much larger screw holes for alignment and clearance. The rivets on the other hand require much smaller holes. The rivets prevent the joint structures from vibrating thus preventing then from vibration damages. Rivets do not loosen, shake out, or back-off as screws and bolts do. As they fill the hole completely and tightly, no possibility of side to side slippage loosening can exist. Locking devices are hence unnecessary.

Machining of the rivets: Because riveting is a simple process, rivets of desired size can be designed to fit the application. Special nose pieces fit narrow spaces, deep holes and crevices, and even right angle applications.

Skill and Cost of riveting: The rivets are little costlier than the screws. But riveting is considerably easy. It can be done by students easily. The cost includes the cost of the gun.

Figure 33: Plates of steel riveted together

Though the rivets cannot be used for joining circuit boards they can be used to fit the metallic main frame of the Satellite. Riveting is the strongest method of fastening the body components of the Satellite. The weight of the rivets is around the same as that of the screws and is much simpler to manufacture than the screws.

Rivets have not been used so much in satellites. As the rivets are installed from one side only, the need for access to both sides of work is eliminated. No more required space for tooling clearance, holding tools, and other "back side" fixture. This allows us to fix the sixth side by using rivets. This also solves the sun sensors problems. Riveting is not presently available at IITB. But it can be easily made available.

Figure 34: Steel rivets that can be used in the satellite

7.2 Helicoils

Helicoil inserts are precision formed screw thread coils of stainless steel wire having a diamond shaped cross section and a good surface finish. When they are installed into Heli-Coil tapped holes, they provide a permanent conventional 60deg internal screw thread that accommodates any standard bolt or screw. Because the Helical insert is larger in diameter than the tapped hole, the insert when it is in place, locks tight. To achieve the installation, the insert reduces in diameter while being screwed into place and expands as soon as the pressure is released on the installation tools.

Figure 35: Helical Inserts

The helicoils can be inserted into any surface. Helicoils prevent vibrations and also loosening of the screws. The helicoils attachments are much stronger than the normal screw attachments. The screws attached to the helicoils do not protrude from the surface as they do not need bolts ence they can be used in efficient designing. We do not need access to both the surfaces if we use helicoils hence we can use them to join the sixth side. They help in multiple removals.

Figure 36: Helicoil with Screw

The helicoils can be inserted into the surface easily with the help of a simple tool kit. Helicoils of different sizes are available according to the need.

Helicoils require much larger holes than normal screw holes. They also add to the stress at the joints. They also add to the weight of the satellite.

The insertion of helicoils is easy. But helicoils are quite costly. Helicoils have not been used much in space missions. They are also heavy and add to the weight of the Satellite. Inserting helicoils requires a simple kit and can easily be made available.

7.3 Screws and Nuts

Screws are the simplest of the fasteners. They are the cheapest of the fasteners and require only a screwdriver and spanner to fit them in. They are the best in terms of multiple removals. They can be used to attach the circuit boards to mechanical harnesses. Screws have been widely used in the space missions until now.

Access to both the sides of the surface is needed to fix the nuts. Hence screws cannot be fixed in angles and crevices or places hard to access. Screws loosen out due to vibrations.

7.3.1 Lock Nut

Forcing a wedge into the gap between the cylinder and its surrounding tube makes it possible to create a powerfully locked assembly. Creating matching key grooves in both the nut and bolt, and then using a hammer to drive a wedge into those grooves does provide a powerful self-locking effect. However, this method is unsatisfactory from the standpoint of operability.

The solution is to use two nuts to play the roles of the hammer and wedge respectively. A small eccentricity in the sliding part of the convex top of the lower nut acts as the wedge. When the concave upper nut is tightened, the effect produced is exactly the same as that produced by a hammer driving in a wedge. Moreover, it is much more effective to use a screw as this makes it very easy to force the wedge into place.

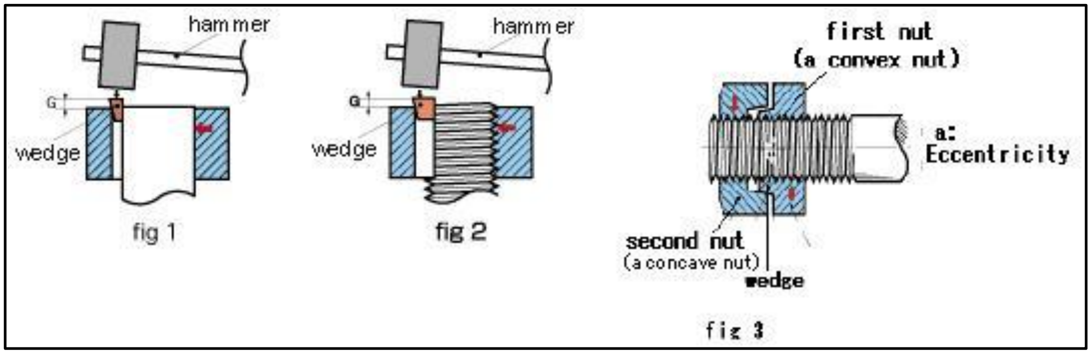


Figure 37: Fixing of Lock Nuts

These nuts fit the bolt very tightly and the effect of vibrations is reduced upto a great extent compared to normal nuts. These are quite heavy. They damage the bolt every time they are fastened and removed. They are even harder to put in unaccessable regions than normal nuts.

7.3.2 Eye nuts

Figure 38: Eye Nuts

These are nuts with an eye in ehich we can insert a bolt to wedge against the inner nut. These nuts fit the bolt very tightly and the effect of vibrations is reduced upto a great extent compared to normal nuts. These are quite heavy. They damage the bolt every time they are fastened and removed. They are even harder to put in unaccessable regions than lock nuts.

7.3.3 Offset nuts

Figure 39: Offset Nuts

Offset nut is a nut that has been deformed at one end so that the threads no longer perfectly circular. The deformed end is usually shaped into an ellipse . The nut is easily started on the male fastener as the bottom portion is not deformed. As the male fastener reaches the deformed section it deforms the threads of the nut elastically back into a circle. This action increases the friction between the nut and the fastener greatly and creates the locking action. Due to the elastic nature of the deformation the nuts can be reused indefinitely.

7.3.4 Fibre inserted nuts

Figure 40: Fibre inserted nuts

A nyloc nut, also known nylon insert lock nut, polymer insert lock nut or elastic stop nut (although incorrectly, as an elastic stop nut is broad class of locking nuts), is a kind of nut that includes a nylon collar insert. The insert is placed at the end of the nut and its inner diameter (ID) is slightly smaller than the major diameter of the screw. The insert deforms over the threads of the screw, but threads are not cut into the nylon. The nylon insert locks the nut in two ways. First, it forces the bottom face of the screw threads against the top face of the nut threads, increase the friction between the two. Second, the nylon applies a compressive force against the screw itself. Nyloc nuts retain their locking ability up to 250 °F (121 °C). The threads of the screw do not damage the nylon insert, therefore they can be reused many times.

7.3.5 Split beam nut

A split beam nut, also known as a split hex nut or slotted beam nut, is a locknut with slots cut in the top that separate the outside end into two or more sections that are bent slightly inward, making the thread diameter undersized in the slotted portion. As the nut is threaded on, these sections are forced back out to their original position and increase the friction between the nut and the fastener, creating the locking action. High strength grades retain their locking ability up to 1,400 °F (760 °C), unlike nyloc nuts. Military grade nuts can be reused at least a dozen times.

Chapter 8: Level II Testing

Level II testing stands for those tests where more than one closely related Sub-Systems come together and perform detailed tests. There are only 4 Level II tests for Pratham, they are:

1. OILS (OBC and Controls)
2. POILS (Power, OBC, Con, Comm, Mech, Therm)
3. Comm (Transmitter, Ground station) and Payload
4. Thermovac of Structural Model (Struct, Therm and Mech)

In this report, only OILS is discussed in detail.

8.1 On Board Computer In Loop Simulation (OILS)

8.1.1 Introduction

OILS (On-board computer In-Loop Simulation), as the name suggests is a setup for simulating the on-board computer with inputs similar to those that it may experience in the satellite. It is part of the second level testing and will help identify bugs and shortcomings of the hardware and software of the On-Board Computer. In short, the objective is as follows:

To setup an arrangement to do hardware in loop simulation of the onboard computer with the exact inputs and outputs it is supposed to receive in space, and thus verify its performance.

8.1.2 Approach

The problem consists of the following parts:

1. Hardware interfacing with the computer.
2. Generation of sensor data to be fed in as input to the OBC and verification of the response of the system against the expected response.

8.1.3 Implementation

The connectivity diagram of the Satellite is shown in the chapter on Wires and Connectors. The connectivity and block diagrams for OILS are as follows.

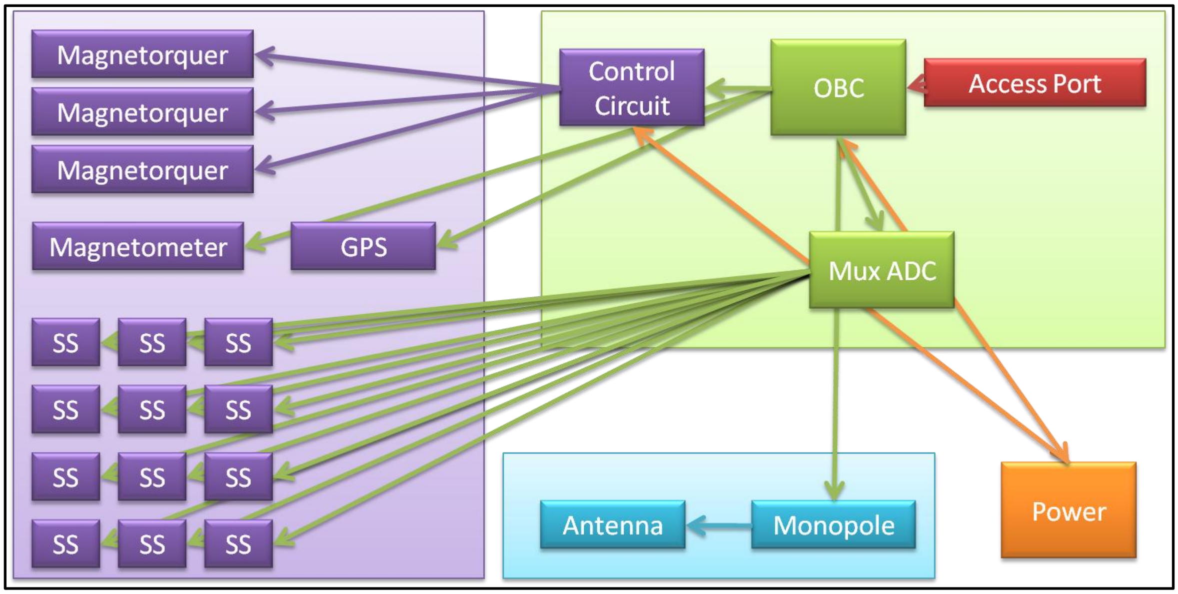


Figure 41: Connectivity Diagram for OILS

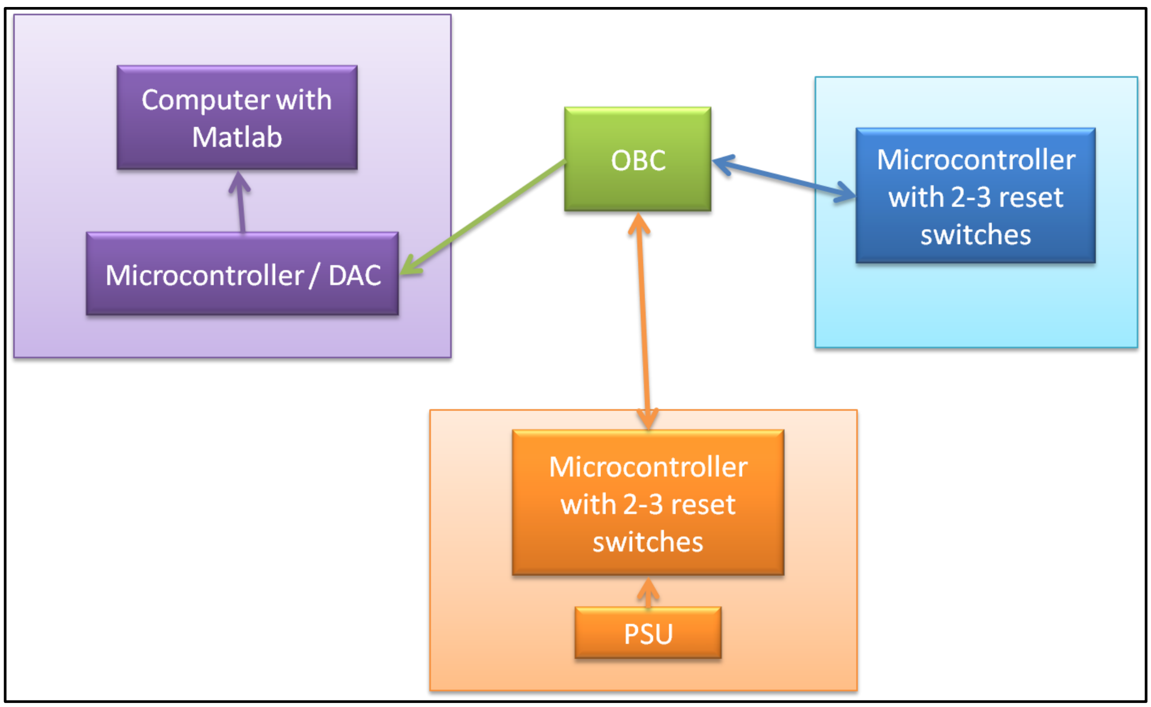


Figure 42: Block Diagram for OILS

As can be seen from the block diagrams, the following modifications were made for OILS:

1. The solar panels were replaced by a Power Supply Unit (PSU).
2. The control components (magnetometer, GPS, magneto-torquer and sun-sensors) were replaced by a computer with matlab and a microcontroller/DAC.

3. The power board has been replaced by a PIC microcontroller giving out a constant health monitoring message instead of sensor dependent health monitoring that the actual power board does.
4. The access port and the umbilical cord are not part of the OILS setup. However they may be added later.

8.1.4 Interfacing with the computer and MATLAB

- The interfacing with the computer is done through a data acquisition card. The following pin requirements are imposed on the data acquisition card:
    - 12 analog outputs For the sun-sensors.
    - 2 serial ports: 1 each for the magnetometer and the GPS.
    - 3 analog inputs: 1 for each of the magneto-torquers.
- Hence, we want to buy a Data Acquisition card with at least 15 analog inputs, 5 analog outputs and 4 serial ports. Other than this, we'd like it to have a high frequency limit.
- MATLAB will be handling the data acquisition card's functioning and writing the system inputs and reading the system outputs.

MATLAB has a data acquisition toolbox which works in the following manner:

- Data is acquired and brought up through the particular hardware vendor's software
- The data is handed off to the Data Acquisition Toolbox engine.
- The data is made available in MATLAB.
- The data is run through whatever control algorithm the user designs in MATLAB.
- The data is then routed back to the engine and down through the hardware vendor's software into the board.

Working in real time on MATLAB
One of the major requirements of setting up a realistic environment such as OILS is to provide the inputs real-time in order to ensure that the responses are timely. With this also comes the requirement of testing the system response as fast. This requirement is fulfilled by using one of the following packages:

- Real-Time Windows Target 3.2
- Real-Time Workshop 7.2
- xPC Traget 4.0

MATLAB Real-time toolbox

One of the options for a real-time toolbox in MATLAB is Humusoft Extended Real Time Toolbox 3.1. It has the following features :

- Real-time kernel with sampling frequencies up to 66 kHz with no external clock source required
- Data acquisition sampling rate up to the speed of your data acquisition board (even over 1 MHz)
- Simulink block library for creating real-time simulations and control loops

Some of the points of concern when the interfacing is being designed are as follows:

- Giving Magnetometer signal as a continuous wave and not as a discretely changing input. To fulfill this, we would want to change the magnetometer signal at a higher frequency (about 10 times) than the frequency at which the signal is read.
- Secondly, GPS is read through an interrupt, hence we will need to figure out whether we can implement interrupts in the real time toolbox.

8.1.5 Tasks on OILS

Since the most important task will be to test the OBC, the OBC will be taken through the Operation sequence. The requirement of operation over 320hrs to remove infant mortality will also be done using OILS. Finally the working of the Control Law and the control of the simulated Satellite using actual torques given by the magnetorqer will also be tested.

8.2 Other Level II Tests

The connectivity diagram for Power and On Board Computer In Loop Simulation (POILS) is shown below. For Mechanical Sub-Systems will make a Structural model. It will undergo both Thermovac and Vibration Testing. The Communication and Payload Sub-Systems will test the entire transmitter and receiver link budget.

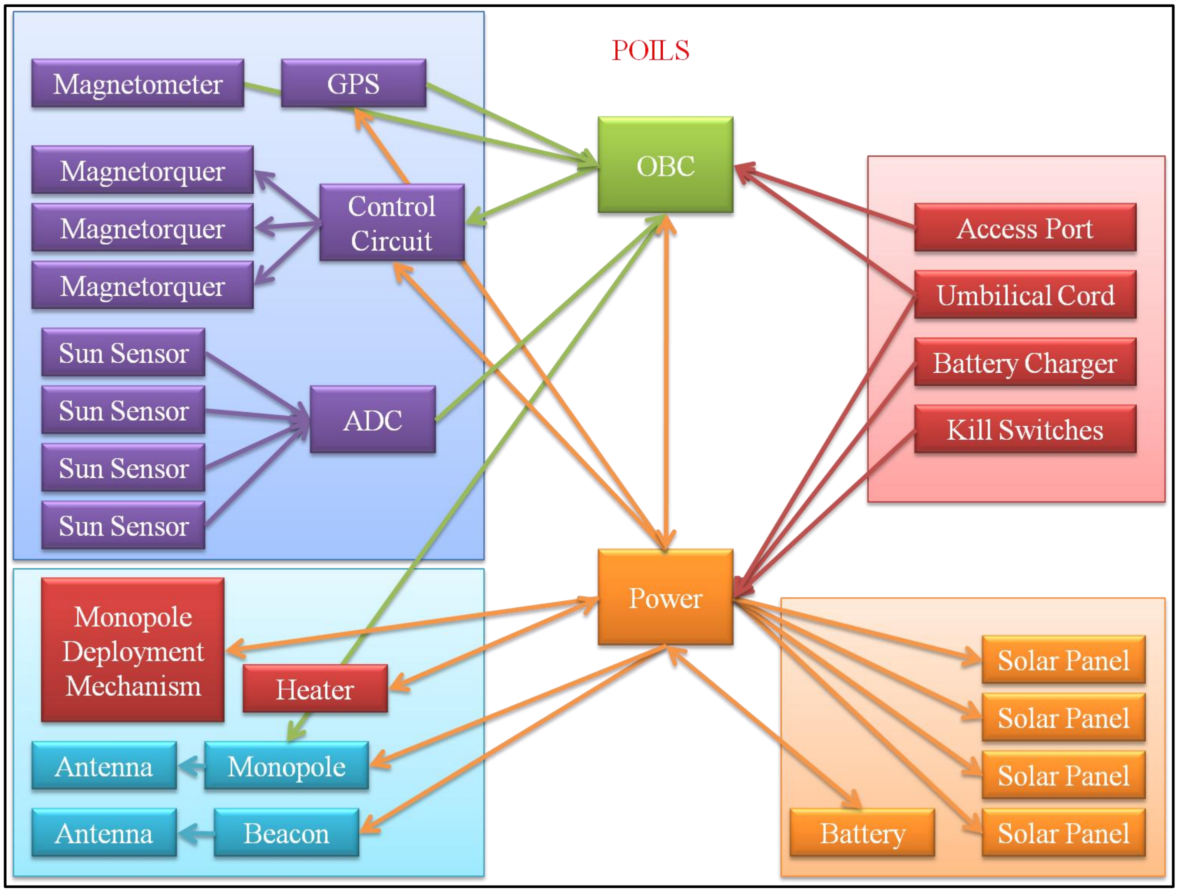


Figure 43: Connectivity Diagram for POILS

Chapter 9: Technical Budgets

9.1 Weight Budget

The weight Budget is as of now not complete as some of the components within the Satellite are suspected to change, like the monopole deployment mechanism might be removed. Hence only some details have been added to the new weight budget (version 2b). In this report we are also attaching the weight budget for CDR (version 1b).

Table 5: Weight Budget (Version 2b)

Name	Weight (gms)	Size (mm)	Specification	Temperature Range (degree C)	Source of Data	Who provides data	Comments	Calculation
Beacon								
Beacon (Monopole 1) antenna	1.74480767	cylinder of l=170mm, radius(a) = 1.15mm	437 MHz, l = 170mm, radius(a) = 1.15mm,		Density of Al6061=2.7g/cc , http://www.matweb.com/search/DataSheet.aspx?MatGUID=626ec8cdca604f1994be4fc2bc6f7f63	Jhonny	Freq: 437MHz , assume Al 6061 cylinder	vol = pi*a^2*l
Monopole harness on satellite						SE		
Connectors for monopole circuit to antenna						SE		
Wires used between monopole circuit to antenna						SE		
Beacon Circuit						Jhonny, Area density. Components on PCB excluding connectors. Soldering thickness and Soldering length.	TBD once the board components are delivered.	
Monopole circuit holders and thermals						SE		
Power connectors coming out of monopole ckt						SE		
Power cable going to the Power ckt						SE		
Connector for Beacon switching on cable						SE		
Data cable going to the OBC ckt or Umbilical cord						SE		
Monopole 2								
Monopole 2 antenna	1.74480767	cylinder of l=178.8mm, radius(a) = 1.2mm	150 MHz, l = 180mm, radius(a) = 1.15mm		Density of Al6061=2.7g/cc , http://www.matweb.com/search/DataSheet.aspx?MatGUID=62	Jhonny	Freq: 150MHz , assume Al 6061 cylinder	vol = pi*a^2*l

					6ec8cdca604f1 994be4fc2bc6f7 f63				
Monopole harness on satellite						SE			
Connectors from monopole circuit to antenna						SE			
Wires used between monopole circuit to antenna						SE			
Monopole 2 Circuit						Jhonny, Area density. Components on PCB excluding connectors. Soldering thickness and Soldering length.	TBD once the board components are delivered.		
Power connectors coming out of monopole ckt						SE			
Power cable going to the Power ckt						SE			
Data connectors coming out of monopole ckt						SE			
Data cable connecting Monopole 2 to OBC ckt						SE			
Monopole Deployment Mechanism									
Mechanism						Mayank			
Nylon Wire						Mayank			
Deployment ciruit and actuator						Mayank, Area density. Components on PCB excluding connectors. Soldering thickness and Soldering length.			
Power connectors						SE			
Power cables to Power ckt						SE			
Data Connectors						SE			
Data cables to OBC						SE			
3.48961534									
Solar Panels									
Individual Solar Panels (sun facing side). size 16cm X 21cm	59.136	210 X 160 X 5	Triple junction solar panels from Spectrolab. Clearance of 1cm from all sides.		Density of Solar Panels = 1.76kg/m2 spectrolab_panels.pdf	Ameya	We are expecting ISRO to give us solar panels of our size. Hence we will be dealing with only the final solar panels per side.	59.136	

							The 5 sides will weigh differently.	
Side1: Solar Panel harness on the satellite						SE		
Side1: Power connectors coming out of this solar panel						SE		
Side1: Power cable going to Power ckt						SE		
Side1: Thermals below panel						Manas		
Individual Solar Panels (zenith). size 21cm X 16cm	59.136	210 X 160 X 5	Triple junction solar panels from Spectrolab. Clearance of 1cm from all sides.		Density of Solar Panels = 1.76kg/m2 spectrolab_panels.pdf	Ameya		59.136
Side2: Solar Panel harness on the satellite						SE		
Side2: Power connectors coming out of this solar panel						SE		
Side2: Power cable going to Power ckt						SE		
Side2: Thermals below panel						Manas		
Individual Solar Panels (Leading velocity). size 21cm X 16cm	59.136	210 X 160 X 5	Triple junction solar panels from Spectrolab. Clearance of 1cm from all sides.		Density of Solar Panels = 1.76kg/m2 spectrolab_panels.pdf	Ameya		59.136
Side3: Solar Panel harness on the satellite						SE		
Side3: Power connectors coming out of this solar panel						SE		
Side3: Power cable going to Power ckt						SE		
Side2: Thermals below panel						Manas		
Individual Solar Panels (lagging velocity) size 21cm X 16cm	59.136	210 X 160 X 5	Triple junction solar panels from Spectrolab. Clearance of 1cm from all sides.		Density of Solar Panels = 1.76kg/m2 spectrolab_panels.pdf	Ameya		59.136
Side4: Solar Panel harness on the satellite						SE		

Side4: Power connectors coming out of this solar panel						SE		
Side4: Power cable going to Power ckt						SE		
Side2: Thermals below panel						Manas		
236.544								
Power Circuit								
Circuit Board						Ameya, Area density. Components on PCB excluding connectors. Soldering thickness and Soldering length.		
Power connectors coming out						SE		
Data connector coming out						SE		
Data cable connecting Power ckt to OBC ckt						SE		
Harness of the Power Ckt onto the satellite						SE		
Thermals around the power ckt						Manas		
0								
Battery								
4 Batteries						Ameya		
Battery box						Ameya		
Power cables to the Power ckt						SE		
Harness of the Battery cage to the satellite						SE		
Passive Thermals around the battery cage						Manas		
Active Heaters around the cage						Manas, Ameya		
Power connectors to supply power to the heaters						SE		
Power cable connecting to power ckt						SE		
Thermal Sensors on the cage						Ameya		
0								
OBC ckt								
Circuit Board						Ashay, Area density. Components on PCB excluding connectors. Soldering thickness and Soldering length.	OBC board also houses the H-bridges for the torquers and the 12 Sun-Sensor circuits	
Power connector coming out						SE		
Power cables going to Power ckt						SE		

Data cables coming out						SE		
Harness of the OBC Ckt onto the satellite						SE		
Thermals around the OBC ckt						Manas		
0								
GPS								
GPS module	20	70*45*12 mm	SGR05; Data Interfaces: UART,PPS outputs: TTL	Tmin = -24deg and Tmax = 61deg	datasheet and answer to the mail by SSTL rep.	Chandrika	Without shield	
harness for the module and thermals						SE		
Power connectors						SE		
Power cables to Power ckt						SE		
Data Connectors						SE		
Data cables to OBC						SE		
antenna		80*80mm base				Chandrika		
harness for antenna						SE		
20								
Magnetometer								
Magnetometer module	98	74.9 x 30.5	HMR2300		www.ssec.honeywell.com/magnetic/datasheets/hmr2300.pdf	Chandrika		
harness for the module and thermals						SE		
Power connectors						SE		
Power cables to Power ckt						SE		
Data Connectors						SE		
Data cables to OBC						SE		
98								
Magnetorquer								
Sun facing side: Mechanical harness, size 18cm X 18cm						SE		
Sun facing side: Coil weight	56	200x200×10	no of turns=100		46 gm+ wt of epoxy(approx 10 gm)	Chandrika		
Sun facing side: connectors on magnetorqer						SE		
Sun facing side: cables to OBC ckt						SE		
Nadir side: Mechanical harness, size 23cm X 18cm						SE		
Nadir side: Coil weight	56	200x200×10	no of turns=100		46 gm+ wt of epoxy(approx 10 gm)	Chandrika		
Nadir side: connectors on magnetorqer						SE		
Sun facing side: cables to OBC ckt						SE		
Leading side: Mechanical harness, size 23cm X 18cm						SE		

Leading side: Coil weight	56	200x200× 10	no of turns=100		46 gm+ wt of epoxy(approx 10 gm)	Chandrika		
Leading side: connectors on magnetorqer						SE		
Sun facing side: cables to OBC ckt						SE		
168								
Sun Sensor								
Sun Sensors						Chandrika		
Harness for Sun Sensors						SE		
Data Connector						SE		
Data Cable to OBC ckt						SE		
0								
Launch Vehicle Interface								
IBL230V2 FE-ring	600					SE		
SNAP circuit						SE		
Power cable to power ckt						SE		
Access Ports								
Connector						SE		
Data cable to OBC ckt						SE		
Battery charger port (connector)						SE		
Power cable to battery						SE		
Access Port: Power Connector						SE		
Power cable to power ckt						SE		
600								
Main Body								
Weight of 6 sides	3900	26cm cube	3mm AL6061		solid works model	SE		
Fastners						SE		
Heat Pipes						Manas		
Thermals						Manas		
Stiffners						Niranjan		
Transportation & Handling Appendages						SE		
3900								
Total	**5026.0 33615**	**gms**						

Table 6: Weight Budget (Version 1b)

Name	**Weight (gms)**	**Size (mm)**	**Specification**	**Temperature Range (degree C)**	**Source of Data**	**Comments**	**Calculation**
Beacon							
Beacon (Monopole 1)	5.033511638	cylinder of l=164.9mm , radius(a)	433 MHz, l = 164.9mm, radius(a) =		Density of SS304=8.03g/cc, http://hypertextb	Freq: 433MHz, assume SS	vol = pi*a^2*l

		= 1.1mm	1.1mm, vol = 626.838mm^3		ook.com/facts/2004/KarenSutherland.shtml	304 tape	
Monopole harness on satellite	10				mayank_deployment.txt		
Connectors from monopole circuit to antenna	10				the compass1 phase B documentation says 10 g for the connectors	should be BNC connectors	
Monopole Circuit	75	10 X 7 X 2	CC1000 IC (9.7 X 4.4 X 0.9 mm, 0.112g)	-40 to 80	Assuming 1.0336 gm/cm2. See G67	For all circuits - 1st estimate without conformal coatings, second estimate with coatings	72.352
Monopole circuit holders and thermals	33.48		Structural harness of Al: height 1cm, width inwards 2cm. L shaped with 2mm. and 4 screws at corners		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	33.48
Power connectors coming out of monopole ckt	10				the compass1 phase B documentation says 10 g for the connectors		
Power cable going to the Power ckt	27.31296	length = 59cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	69
Connector for Beacon switching on cable	10				the compass1 phase B documentation says 10 g for the connectors		
Data cable going to the OBC ckt or Umbilical cord	18.20864	length = 41cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	46
Monopole 2							
Monopole 2	6.495237828	cylinder of l=178.8mm, radius(a) = 1.2mm	400 MHz, l = 178.8mm, radius(a) = 1.2mm, vol = 626.838mm^3		Density of SS304=8.03g/cc, http://hypertextbook.com/facts/2004/KarenSutherland.shtml	Freq: 400MHz, assume SS 304 tape	vol = pi*a^2*l
Monopole harness on satellite	10				mayank_deployment.txt		
Connectors from	10				the compass1	should be	

monopole circuit to antenna					phase B documentation says 10 g for the connectors	BNC connectors	
Monopole Circuit	75	10 X 7 X 2	CC1000 IC (9.7 X 4.4 X 0.9 mm, 0.112g)	-40 to 80	Assuming 1.0336 gm/cm2. See G67	For all circuits - 1st estimate without conformal coatings, second estimate with coatings	72.352
Monopole circuit holders and thermals	33.48		Structural harness of Al: height 1cm, width inwards 2cm and 4 screws at corners		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	33.48
Power connectors coming out of monopole ckt	10				the compass1 phase B documentation says 10 g for the connectors		
Power cable going to the Power ckt	18.20864	length = 41cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	46
Data connectors coming out of monopole ckt	10				the compass1 phase B documentation says 10 g for the connectors		
Data cable connecting Monopole 2 to OBC ckt	27.31296	length = 59cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	69
Monopole Deployment Mechanism							
Surface	189	200 X 180, thickness = 3mm	carbon fiber		density = 1.750g/cc, http://en.wikipedia.org/wiki/Carbon_fiber	The 2 monopoles will be embedded into it	189
Mechanism	50		hinge: 20gm, 2 X spring: 15gm each		http://www.solarbotics.com/products/tact2/, http://www.pastiron.co.uk/productPage.asp?line=hinges		50
Magnetometer	94	75 X 33 X 5			HMR2300		
Power connectors	10				the compass1 phase B		

					documentation says 10 g for the connectors		
Power cables to Power ckt	18.20864	length = 41cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	46
Data Connectors	10				the compass1 phase B documentation says 10 g for the connectors		
Data cables to OBC	27.31296	length = 59cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	69
798.0535495							
Solar Panels							
Individual Solar Panels (Side 1) opposite nadir surface, i.e. top surface. size 18cm X 18cm	45.056	160 X 160 X 5	Triple junction solar panels from Spectrolab. Clearance of 1cm from all sides.		Density of Solar Panels = 1.76kg/m2 spectrolab_panels.pdf	We are expecting ISRO to give us solar panels of our size. Hence we will be dealing with only the final solar panels per side. The 5 sides will weigh differently.	45.056
Side1: Solar Panel harness on the satellite	142.236		Structural harness of Al: height 1cm, width inwards 2cm. L shaped. + shaped view with 4 hollows in between. 9 screws at all corners		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	142.236
Side1: Power connectors coming out of this solar panel	10				the compass1 phase B documentation says 10 g for the connectors		
Side1: Power cable going to Power ckt	9.10432	length = 20.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	23
Side1: Thermals below panel	76.8					MLI density must be	

						below 0.3gm/cm2	
Individual Solar Panels (Side 2) side with the power ckt. size 23cm X 18cm	59.136	210 X 160 X 5	Triple junction solar panels from Spectrolab. Clearance of 1cm from all sides.		Density of Solar Panels = 1.76kg/m2 spectrolab_panels.pdf		59.136
Side2: Solar Panel harness on the satellite	164.916		Structural harness of Al: height 1cm, width inwards 2cm. L shaped. + shaped view with 4 hollows in between. 9 screws at all corners		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	164.916
Side2: Power connectors coming out of this solar panel	10				the compass1 phase B documentation says 10 g for the connectors		
Side2: Power cable going to Power ckt	4.55216	length = 11.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	11.5
Side2: Thermals below panel	100.8					MLI density must be below 0.3gm/cm2	
Individual Solar Panels (Side 3) side with the OBC ckt. size 23cm X 18cm	59.136	210 X 160 X 5	Triple junction solar panels from Spectrolab. Clearance of 1cm from all sides.		Density of Solar Panels = 1.76kg/m2 spectrolab_panels.pdf		59.136
Side3: Solar Panel harness on the satellite	164.916		Structural harness of Al: height 1cm, width inwards 2cm. L shaped. + shaped view with 4 hollows in between. 9 screws at all corners		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	164.916
Side3: Power connectors coming out of this solar panel	10				the compass1 phase B documentation says 10 g for the connectors		
Side3: Power cable going to Power ckt	18.20864	length = 41cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	46
Side3: Thermals	100.8					MLI density	

below panel						must be below 0.3gm/cm2	
Individual Solar Panels (Side 4) side with the GPS module and one Monopole (assume Monopole 2 as it is smaller) size 23cm X 18cm	59.136	210 X 160 X 5	Triple junction solar panels from Spectrolab. Clearance of 1cm from all sides.		Density of Solar Panels = 1.76kg/m2 spectrolab_panels.pdf		59.136
Side4: Solar Panel harness on the satellite	164.916		Structural harness of Al: height 1cm, width inwards 2cm. L shaped. + shaped view with 4 hollows in between. 9 screws at all corners		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	164.916
Side4: Power connectors coming out of this solar panel	10				the compass1 phase B documentation says 10 g for the connectors		
Side4: Power cable going to Power ckt	18.20864	length = 41cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	46
Side4: Thermals below panel	100.8					MLI density must be below 0.3gm/cm2	
Individual Solar Panels (Side 5) side with the big monopole (beacon, assumed!) size: 23cm X 18cm	59.136	210 X 160 X 5	Triple junction solar panels from Spectrolab. Clearance of 1cm from all sides.		Density of Solar Panels = 1.76kg/m2 spectrolab_panels.pdf		59.136
Side5: Solar Panel harness on the satellite	164.916		Structural harness of Al: height 1cm, width inwards 2cm. L shaped. + shaped view with 4 hollows in between. 9 screws at all corners		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	164.916
Side5: Power connectors coming out of this solar panel	10				the compass1 phase B documentation says 10 g for the connectors		
Side5: Power cable going to Power ckt	27.31296	length = 20.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of	69

						the inner wires.	
Side5: Thermals below panel	100.8					MLI density must be below 0.3gm/cm2	
1690.88672							
Power Circuit							
Circuit Board	150	100 X 70 X 20	2 PCBs			PCB density: 1.0336gm/cm2	
Power connectors coming out	220		22 power cables come out from this baord		the compass1 phase B documentation says 10 g for the connectors.	16 power cables are coming out from here going to other ckts that draw power: 2 to monopole ckts, 1 to battery heater, 1 obc ckt, 1 GPS ckt, 3 magnetorquer ckts, 1 GG Boom ckt, 1 umbilical cord to launch vehicle, 6 to sun sensors. 6 power cables give power to the ckt: 1 from battery, 5 from solar panels	220
Data connector coming out	10				the compass1 phase B documentation says 10 g for the connectors		
Data cable connecting Power ckt to OBC ckt	18.20864	length = 41cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	46
Harness of the Power Ckt onto the satellite	66.96		Structural harness of Al: height 1cm, width inwards 2cm and 4 screws at corners. 2 independent PCB harness		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	33.48
Thermals around the power ckt	21					MLI density must be below 0.3gm/cm2	
486.16864							

Battery							
4 Batteries	600	18.5 X 60 X 65 per battery, 72ml	Saft company, MPS176065	0 - 40	A0154-08.pdf SAFT datasheet, space_li-ion.pdf datasheet		150gms each
Battery cage	73.1808	2mm thick box: inner 60 X 65 X 74, outer 62 X 67 X 76	2mm thick box around the 4 batteries stacked vertically		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	73.1808
Power cables to the Power ckt	10				the compass1 phase B documentation says 10 g for the connectors		
Harness of the Battery cage to the satellite	33.48		Structural harness of Al: height 1cm, width inwards 2cm and 4 screws at corners.		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	33.48
Passive Thermals around the battery cage	78.9					MLI density must be below 0.3gm/cm2	
Active Heaters around the cage							
Power connectors to supply power to the heaters	10				the compass1 phase B documentation says 10 g for the connectors		
Power cable connecting to power ckt	9.10432	length = 20.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	23
Thermal Sensors on the cage	10		LM19				
824.66512							
OBC ckt							
Circuit Board	75	100 X 70 X 20	PCB board 15 gm, Micro-controller 0.8 gm, RAMs(3) 3 gm, PROM 1 gm, Solder 1 gm, Resistors(10) 0.5 gm, Capacitors(20) 1 gm, Total 22.3 gm		omkar_weight_budget.txt	Vishal's thin optimized PCB of size 81X43 weighs 24gms. It has things like pressure sensors, but even we have components. Hence ours 100X70 PCB is minimum 48gm. Hence i am assuming 1.5 times. Hence i am assuming	

						1.0336gm/cm2 for our PCBs.	
Rate gyro	10	7 X 7 X 3			ADXR150		
Power connector coming out	10				the compass1 phase B documentation says 10 g for the connectors		
Power cables going to Power ckt	16.22944	length = 41cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	41
Data cables coming out	120		12 data cables coming out from this board		the compass1 phase B documentation says 10 g for the connectors	12 data cables coming out and going to different ckts: 1 beacon switching on ckt, 1 monopole ckt, 1 power ckt, 1 from GPS, 1 from GGBoom ckt, 1 from umbilical cord, 6 from sun sensor	120
Harness of the OBC Ckt onto the satellite	33.48		Structural harness of Al: height 1cm, width inwards 2cm and 4 screws at corners. 2 independent PCB harness		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	33.48
Thermals around the OBC ckt	21					MLI density must be below 0.3gm/cm2	
285.70944							
GPS							
GPS module	20	70 X 70 X 30			ACCORD		
harness for the module and thermals	25.164		Structural harness of Al: height 1cm, width inwards 2cm and 4 screws at corners. 2 independent PCB harness		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	25.164
Power connectors	10				the compass1 phase B documentation says 10 g for the connectors		

Power cables to Power ckt	18.20864	length = 41cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	46
Data Connectors	10				the compass1 phase B documentation says 10 g for the connectors		
Data cables to OBC	27.31296	length = 59cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	69
antenna (if any)							
harness for antenna (if any)							
110.6856							
Magnetorquer							
Side1: Mechanical harness, size 18cm X 18cm	34.02	4 sides with 2mm width, 21cm length and 5mm thickness			Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp		34.02
Side1: Coil weight	31.7780625	Cu coil of 0.3mm dia and 100 turns				Cu density: 8.92g/cc	31.7780625
Side1: Power connectors	10				the compass1 phase B documentation says 10 g for the connectors		
Side1: Power cables to Power ckt	9.10432	length = 20.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	23
Side2: Mechanical harness, size 23cm X 18cm	34.02	4 sides with 2mm width, 21cm length and 5mm thickness			Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp		34.02
Side2: Coil weight	31.7780625	Cu coil of 0.3mm dia and 100 turns				Cu density: 8.92g/cc	31.7780625
Side2: Power connectors	10				the compass1 phase B documentation says 10 g for the		

					connectors		
Side2: Power cables to Power ckt	4.55216	length = 11.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	11.5
Side3: Mechanical harness, size 23cm X 18cm	34.02	4 sides with 2mm width, 21cm length and 5mm thickness			Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp		34.02
Side3: Coil weight	31.7780625	Cu coil of 0.3mm dia and 100 turns				Cu density: 8.92g/cc	31.7780625
Side3: Power connectors	10				the compass1 phase B documentation says 10 g for the connectors		
Side3: Power cables to Power ckt	18.20864	length = 41.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	46
259.2593075							
Sun Sensor							
Sun Sensor	60	6 X 6.4	6 SS on all sides.		SLSD-71N8/S6560	Assume each weighs 10gm	60
Temp Sensor	60		6 Temp sensors on all sides			Assume each weighs 10gm	60
Harness for Sun Sensors	159.1488		6 harnesses, Structural harness of Al: height 1cm, width inwards 2cm and 4 screws at corners. 2 independent PCB harness		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp	weight of each screw =1gm	159.1488
Power connector	60		6 connectors		the compass1 phase B documentation says 10 g for the connectors		
Power cable to Power ckt	68.2824		Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	172.5
Data Connector	60		6 connectors		the compass1 phase B documentation		

					says 10 g for the connectors		
Data Cable to OBC ckt	68.2824		Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	172.5
535.7136							
Launch Vehicle Interface							
Mechanical Harness on Side6: Nadir surface, size 18cm X 18cm	248.4	10 X 10 X 230	4 rails of 1cm square cross-secton, along 4 edges		Density of AL 6061=2.7gm/cc, http://www.suppliersonline.com/propertypages/6061.asp		248.4
Umbilical Cord: Power Connector	10				the compass1 phase B documentation says 10 g for the connectors		
Power cable to power ckt	9.10432	length = 20.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	23
Umbilical Cord: Data Connector	10				the compass1 phase B documentation says 10 g for the connectors		
Data cable to OBC ckt	9.10432	length = 20.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	23
Mechanical Switches	40					to detect the satellite is launched	
Access Ports							
Connector	10				the compass1 phase B documentation says 10 g for the connectors		
Data cable to OBC ckt	9.10432	length = 20.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	23
Battery charger port (connector)	10				the compass1 phase B		

					documentation says 10 g for the connectors		
Power cable to battery	9.10432	length = 20.5cm	Teflon wire of 5mm outer dia and 2mm inner dia. Linear density is 0.39584g/cm		Density of Teflon = 2.2g/cc, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=227	We will use 2.4g/cc since we should also consider the addition of weight because of the inner wires.	23
364.81728							
Main Body							
Weight of 6 sides	1700	230 X 230 X 230			Solid works	As per final config layout	
Fastners	50					50 screw, each 1gm	
Heat Pipes							
Thermals							
Stiffners							
Transportation & Handling Appendages							
1750							
Total	**7105.959257**	**gms**					

9.2 Power Budget

The Power Budget is made by the Power Team.

Table 7: Power Budget

Circuit	**Energy consumed (W-hr)**
Beacon	12.023
Downlink	3.410
GPS	7.200
Gyroscopes	0.420
Sun Sensors	1.200
Magnetometer	5.760
Magneto-torquer	12.420
Torquer driver	0.390
OBC	23.760
Battery Heater	28.889
Total	**95.472**

9.3 Data Budget

The Data Budget is the Total Data that will be stored and transmitted back to Ground Station. The communication channel can send an average of 63 KB of data everyday.

Table 8: Data Budget

Sub-System	**Description**	**Type (bits)**	**Total bits**	**Freq (once in these many mins)**	**Total bits**	
Power	10 bytes	8 bits each	56	1.5	53760	
OBC	Time	min = 6, hour = 5, date = 5, month = 4, year =2, so total = 22 bits for date.	24	1.5	23040	
Controls	Attitude and	floats (16 bits	96	1.5	92160	

	Position (6)	each)				
Total data per day					168960	bits
					20.625	KB
Hamming codes	8/4 times				337920	bits
					41.25	KB
AX25	20 bytes for every 255 bytes		number of packets	166	45560	bits
Total bits per day					44.49219	KB
	Each Data packet contains	22	bytes			
	This will be packaged into ax25 packets of 255 bytes per packet	11	bytes per packet			
	With 23 bytes left over					

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