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PRATHAM
IIT BOMBAY STUDENT SATELLITE

Report
Power Subsytem

By

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Chapter 1

Introduction

1.1 Pratham Overview

Pratham is the first satellite designed and built by the IIT Bombay Student Satellite Project. It's defining features are as follows:

- Weight: under 9.7 Kg (excluding the mass of the FE ring)
- Size: 28.9 cm $\times$ 29.9 cm $\times$ 46.1 cm
- Solar Panels on 4 sides
- Orbit: 10:30 polar sun-synchronous
- Three pre-deployed monopoles
- Downlink at frequency 437.455 MHz
- Beacon at frequency 145.98 MHz
- Uplink at frequency 437.455 MHz
- Completely autonomous

1.2 Mission Objectives

The main aim of Pratham is to measure the Total Electron Count (TEC) over India. It is also recognized that the learning and experience gained from this endeavour is quite valuable by itself regardless of the data obtained from the TEC measurements. The mission statement has, therefore, been broken down into of various levels. The successful completion of each level adds to the overall success of the mission.

1.3 Power Sources

The main sources of power for a space mission are

- Solar power
- Chemical power (non-rechargeable cells, fuel cells)
- Nuclear power

Chemical power is suitable only for short missions and nuclear power is suitable only for large missions with large power requirements. For small satellites like Pratham, with a designed lifetime of a few months to a few years, solar power is the most suitable source of power. Recent advancements in solar cell technology make it possible to harness Sun's energy with considerable efficiency (around 25%). Newer cells based on Gallium Arsenide (GaAs) have higher efficiencies as compared to Silicon (Si) cells and also degrade slower in the harsh space environment.

1.4 Power Budget Summary

Power SubSupply	**Supply Voltage (V)**	**Load Current (mA)**	**Load Power (W)**
BEACON	5.00	548.60	2.74
DOWNLINK	5.00	460.82	2.30
CONTROL /TORQ	3.60	865.70	3.12
OBC	3.30	24.77	0.08
GPS	5.00	400.10	2.00
Battery	8.40	130.84	1.10
		Total Power Budget	11.35

Table 1.1: Power Budget Summary

Notes:

- The magnetometer won't be ON whenever the magnetorquers (actuators) are ON.
- The magnetometer has a supply voltage of 8.4 V and a supply current of 35mA, making the total power consumption as 0.29 W.
- Therefore, maximum power consumption with magnetometer ON is 8.52 W.

1.5 Incident radiation

The satellite receives light from three sources:

- Direct solar radiation
- Sunlight reflected from Earth
- Earth's thermal radiation

Direct solar radiation is the major component of these. Power available from solar radiation is calculated analytically. The total useful power on each of the faces is found to be:

A	A'	B	B'	C	C'	Total
14W	1W	10W	8W	12W	0W	45W

Table 1.2: Incident radiation

Faces

- A=Nadir
- A'=Zenith
- B=Lagging
- B'=Leading
- C=Sun-Side
- C'=Anti-sun side

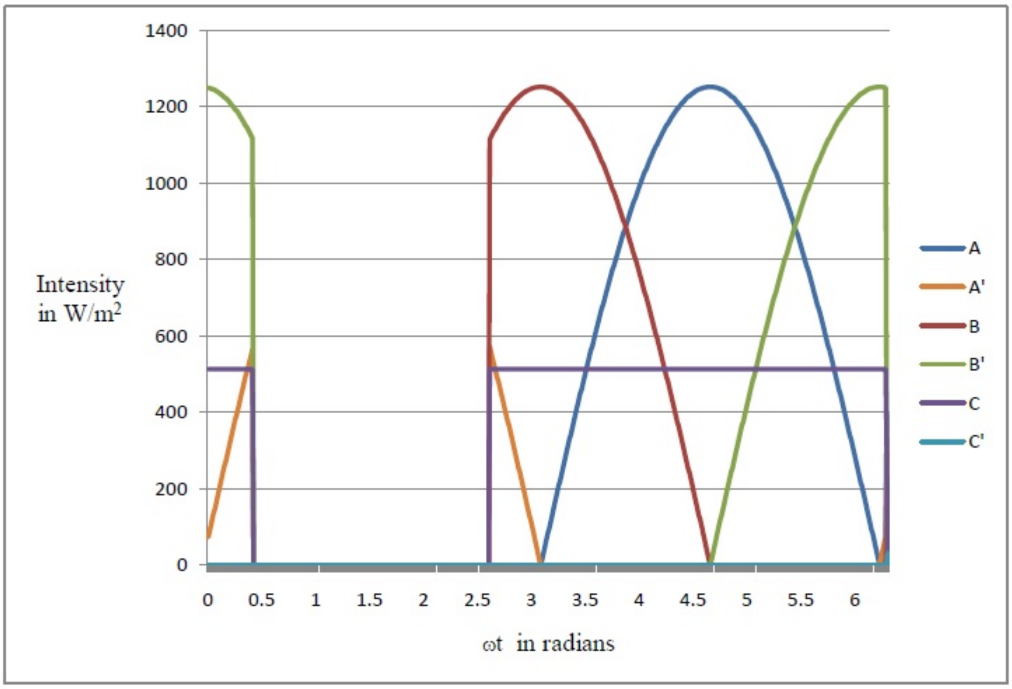


Figure 1.1: Solar intensity

Source: Virtual Lab

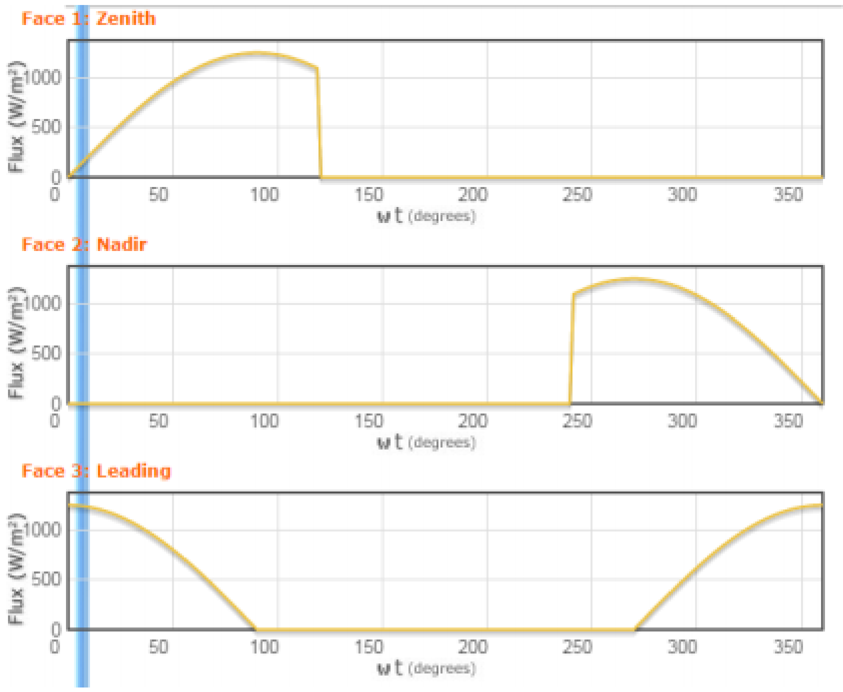


Figure 1.2: Solar intensity-1

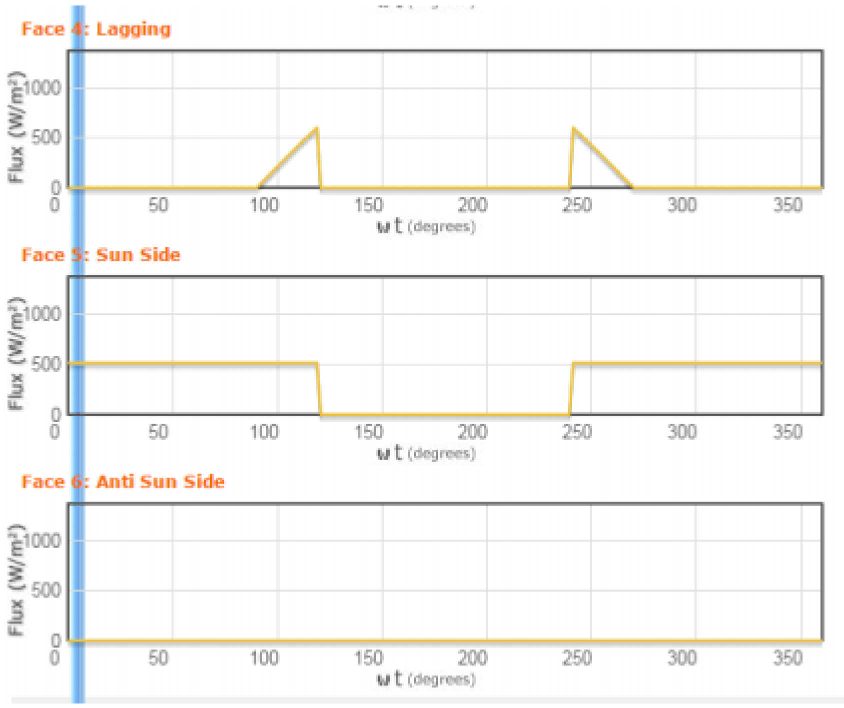


Figure 1.3: Solar intensity-2

Source: Virtual Lab

Chapter 2

Power Requirements

2.1 Requirements from On Board Computer Sub-System imposed on Power Sub-System

- Power Sub-System should send Health Monitoring (HM) data received from loads,current sensors and battery when the OBC polls for data. Note that HM data does not include temperature data

- Power Sub-System shall inform OBC Sub-System if some component misbehaves (over-current) and has to be shutdown. The decision to shut it down shall be taken by the On Board Computer (OBC) unless it is the OBC itself which misbehaves.

- For the case when the OBC itself experiences over-current, Power Board will shut it down and decide when to start it again

2.2 Requirements from Integration Sub-System imposed on Power Sub-System

- The size of the circuit board should be 12cm X 12cm.

- 1cm border shall be left on all sides along with a central square of 1cm, and it must be grounded.

- In the region which is 0.7cm from the circuit bottom, and tall components should not be mounted.

2.3 Requirements from Power Sub-System imposed on On Board Computer Sub-System

- OBC Sub-system should poll for HM Data every two seconds.
- OBC Sub-System shall update Power Sub-System every two seconds, with the list of components that should be turned ON or OFF.

2.4 Requirements from Power Sub-System imposed on Integration Sub-System

- Integration Team should place solar panels on the 4 sides, namely sun-side, zenith, leading side and lagging side.

- Integration Team should feed the incoming power coming from the solar panels to the power board via two connectors

- Integration Team shall make sure that shadows due to other deployed parts shall not fall on the solar panels.

2.5 Requirements from Power Sub-System imposed on Attitude Determination and Controls Sub-System

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

2.6 Requirements from Power Sub-System imposed on Thermals Sub-System

- Thermals Sub-System should protect the solar panels from heating above 70^oC.

- They should maintain the temperature range of the battery within 0^oC to 30^oC.

- They should maintain the temperature of the board within the operating temperature range of the components(industrial grade) i.e. -40^oC to $+85^o$C.

Chapter 3

Depth of Discharge

3.1 Charging/Discharging of Battery

Table ?? shows the load values for calculation of power consumption. This does not include power requirement of magnetorquer as it is calculated in the matlab code which runs the attitude determination and controls simulations. The condition for battery charging depending on the cell voltage and the power from solar panels is as follows:

- Incoming solar power greater than power consumption AND
- Cell voltage less than 4.1 V if battery is in discharging mode in previous time step OR
- Cell voltage less than 4.2 V if battery is in charging mode in previous time step

3.2 Switching Condition

- Start the GPS when the average moment drops below a threshold (0.04 N-m/T) and remains there for some duration (0.4times Orbital period)
- GPS must be off in eclipse region because of power constraints.
- In light region, GPS is switched on periodically after every 10 minutes and kept on for 2 minutes.
- The switching from detumbling to nominal mode is decided by the estimated angular rates.

3.3 Simulation results for DOD for various altitudes

Detumbling mode is characterised by high angular rates and hence power generation through solar panels will take place with a lower efficiency in detumbling than in nominal mode. Accordingly, simulations are carried out for two cases for the altitude of 500 km with initial angular rates of [5,5,5] deg./s:

1. The battery does not get charged at all in detumbling mode (worst case scenario)
2. The power generation of solar panels in detumbling mode takes place with an efficiency lower than that in nominal mode. Since the exact efficiency is difficult to estimate, it is taken as half of nominal mode. Nominal mode efficiency is 16%. Therefore, for this case, the efficiency in detumbling mode is taken as 8%.

The initial DOD is determined by the current drawn by the electric switch SNAP circuit. Since electrical switch SNAP uses only 100 μA current, the battery will lose less than 0.036 % of its charge per day. Even in the case of delayed launch of one month or so, battery will drain approximately 1 % of its charge. Hence, corresponding to this worst case scenario, the initial DOD is taken to be 0.01. The following are the essential outputs obtained:

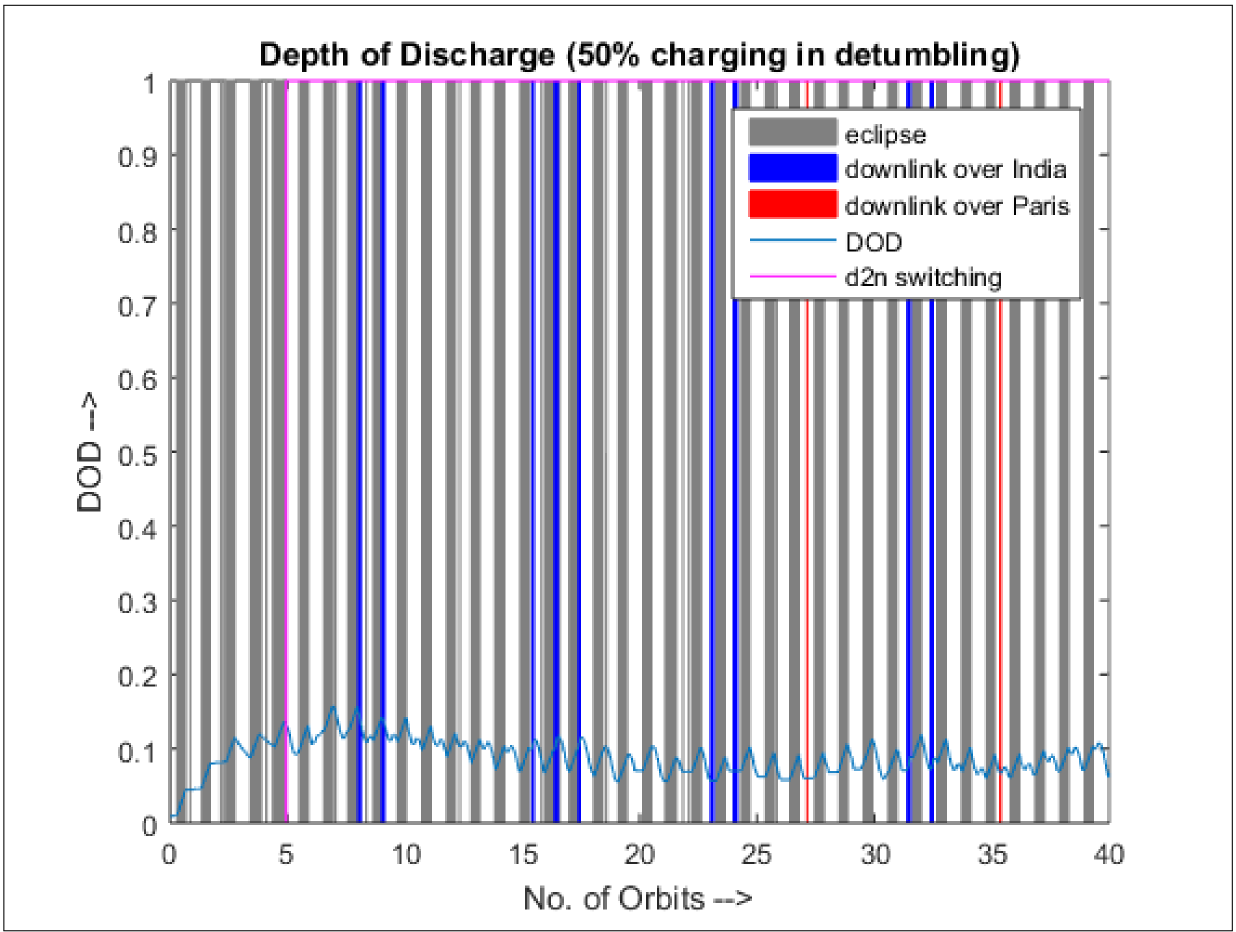


Figure 3.1: Solar power efficiency of 8% in detumbling

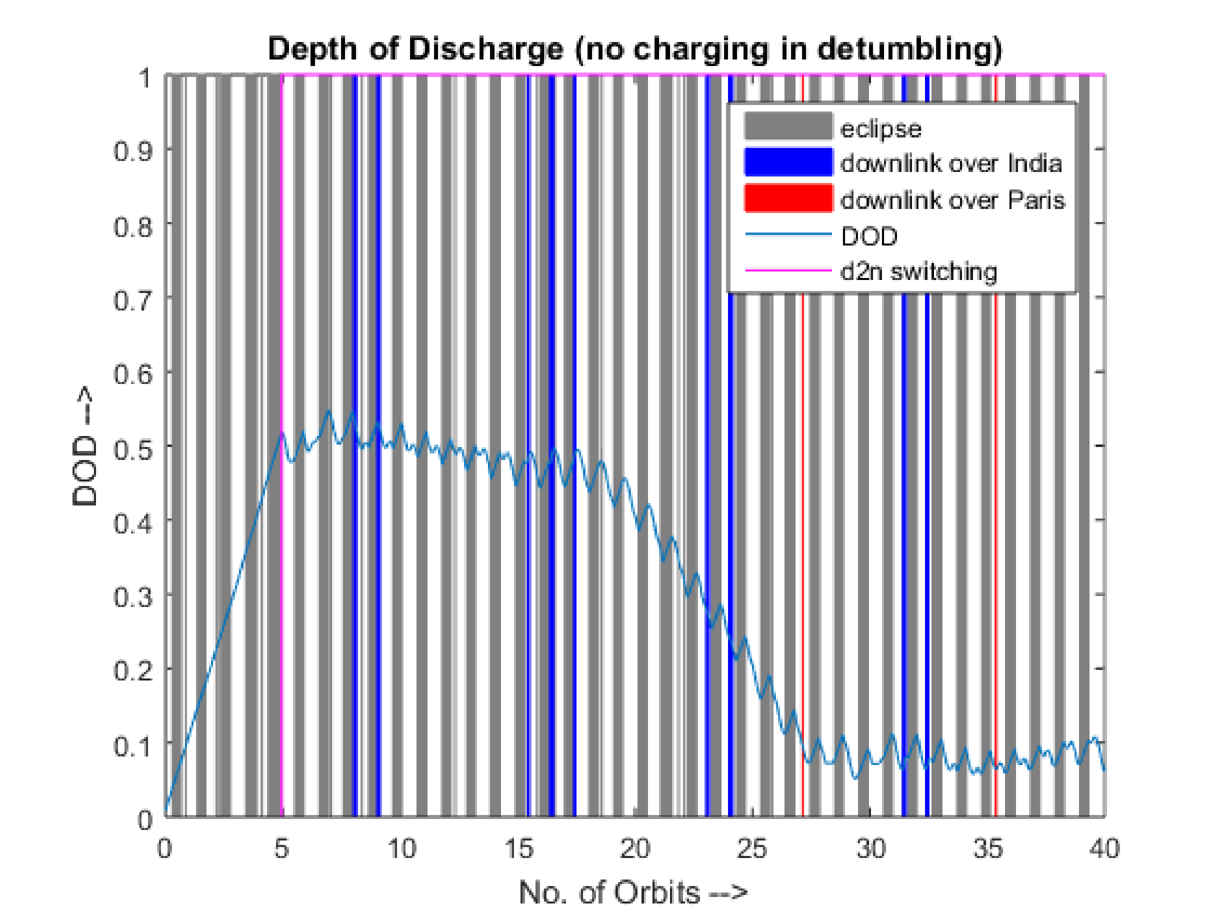


Figure 3.2: No Solar Power in Detumbling

3.3.1 Inference

- DOD value reaches to a maximum of 0.15 in the case of charging during detumbling (Fig. ??) and 0.55 in the absence of charging during detumbling (Fig. ??).
- In the case of no charging during detumbling, DOD reaches upto 0.55 after initial detumbling(Fig. ?? and Fig. ??). But after about 20 orbits, it starts to decrease and then remains within 0.15 for subsequent orbits.
- In the case of charging during detumbling, the DOD does not shoot up to a high value during initial detumbling
- The actual scenario will be somewhere between the two cases, since the efficiency of charging during detumbling will steadily increases as the angular rates continue to decreases. So, even for the worst case scenario, DOD is within 55 %.

Chapter 4

Flight Hardware

Now we describe the hardware to be used on the satellite

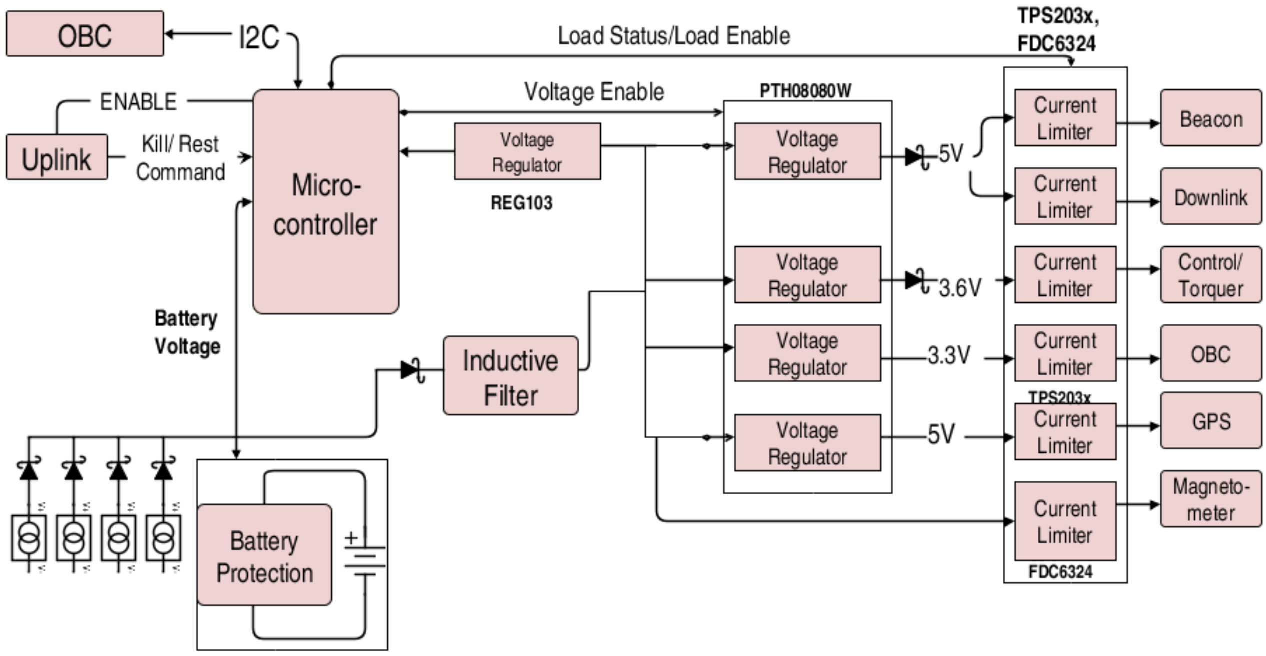


Figure 4.1: Schematic of the Power Board

Four solar panels with reverse blocking diodes are connected to the battery bus. The batteries are connected in a 2-series 3-parallel configuration for redundancy and have protection circuits on them. Voltage regulators step down the battery voltage to 5V, 3.6V and 3.3V. There are current limiting switches in series with each load to ensure shut-down in case of excessive power drawn by that particular load.

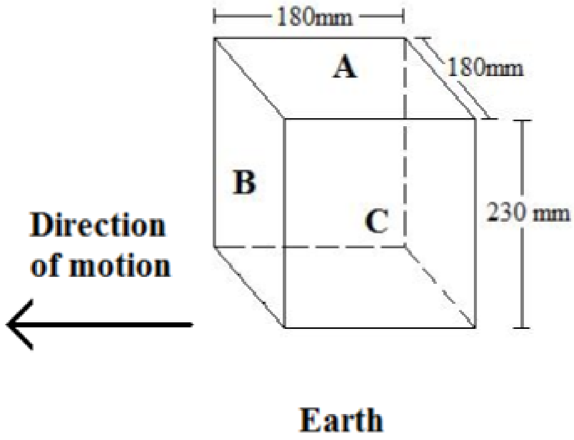
4.1 Solar Cells

The satellite is powered by solar panels on four faces. One of the side faces is reserved for the antennae and another for launch vehicle interface.

Rough values of characteristics of solar cells are as follows (all characteristics at intensity of 1353 W/m^2 and Temperature: 28°C):

- Open Circuit Voltage (V_{OC}): 1010 mV
- Voltage at maximum power(V_{MP}): 870 mV

- Short Circuit Current(I_{SC}): 260 mA
- Current at maximum powerI_{MP}: 235 mA
- Maximum Efficiency: 18%
- Dimensions: 20.25 mm (± 0.05mm) x 40.25 mm (± 0.05 mm)



4.2 Solar Panel

The faces A, B, B' will have 44 cells each and the face C' (zenith) has 33 cells to make space for GPS antenna. All faces have the cells connected in strings of eleven cells in series. Hence, faces A, B, B' have 4 such strings while the C' face has 3 such strings. Since no sunlight ever falls on the face A' (anti sun-side), that face has been used for the antennae, while the face C (nadir) has been used for Launch Vehicle interface.

The voltage ratings of all the panels are the same: V_{OC} = 11.1V and V_{MP}= 9.57V. Panels are designed to have such high V_{MP} because at higher temperature this value falls. Since, MPPT is not used, if V_{MP} falls below battery voltage, very low power output is obtained. The maximum temperature of the solar panels is calculated by the thermals team to be around 35°C. Hence we shall assume room temperature values for all subsequent calculations.

10mm Aluminum honeycomb is proposed to be used as base for the panel. Size of the panels will be approximately 22cm x 22cm.

4.3 Battery Pack

Rechargeable lithium-ion technology has been selected for the satellite considering their superior performance and characteristics over the other battery technologies like nickel cadmium (NiCd) and nickel metal hydride (NiMH). 18650 cylindrical Lithium Ion cells are chosen. The cells will be provided by ISRO. Above mentioned cells have the following characteristics:

They will be assembled into a 2-series 3-parallel pack. Thus, the total rating of the battery is:

- Guaranteed Capacity: 6.6 Ah
- Maximum Voltage on Charge: 8.4 V
- Minimum Voltage on Discharge: 6.0V
- Depth of Discharge: 10% to 40%
- Mass: 317 gm
- Dimensions ($L * B * H$): $35mm * 40mm * 75mm$ (excluding harness)

4.4 Battery Charge Regulation and Protection

The ideal charging method for Li-ion batteries is a constant-current, constant voltage (CCCV) charging algorithm. In this method, the battery is charged with a constant current (1 A) until the voltage reaches the end-of-charge (EOC) voltage. Once the EOC voltage is reached, the charger switches to a constant voltage charging where the charging current automatically falls with time. The battery is declared "charged" when the charging current drops to a predetermined limit. The limit is determined by the charge management IC.

The varying sunlight intensity makes it impossible to maintain the CCCV algorithm always. Hence, it was decided not to use any dedicated battery charger IC but to use a combination of the microcontroller and the battery protection cum charge regulation IC for regulating the battery charging.

The IC BQ2057W from the Texas Instruments was selected to serve our purpose. The IC has overvoltage protection thresholds which are suitable for our Li-ion dual cells with an EOC voltage of 8.4V. The specifications of BQ2057W are:

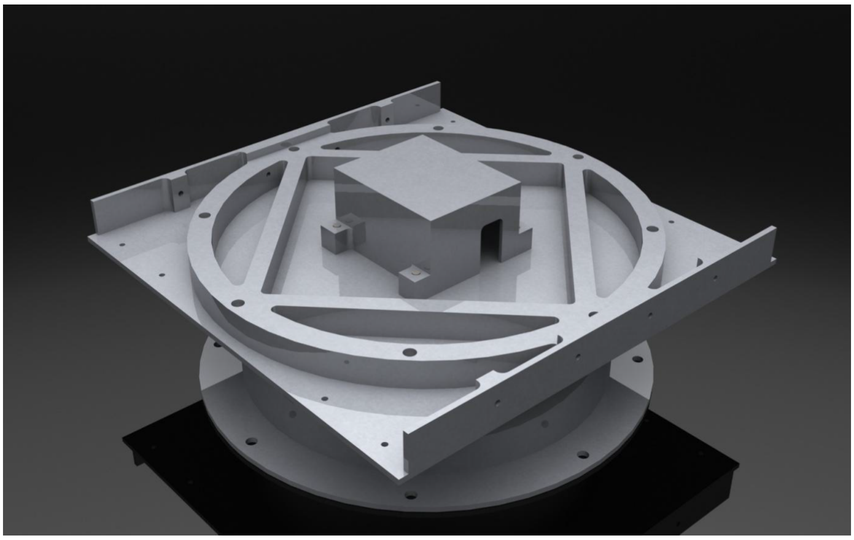
- Better than ±1% Voltage regulation accuracy with preset voltages
- Provides three phases of charging: Conditioning, Constant Current and Constant Voltage
- Protects Sensitive Lithium-Ion and Lithium-Polymer battery from overcharging.
- Charge Recharge Threshold of V_{REG} - 0.2V

- Recommended Operating Supply Voltage Range of 4.5V to 15V. The solar panel voltage falls well within this range.
- Operating free-air temperature range of -20 to 70°C.
- Total Power Dissipation: 300mW at 25°C
- External pass-transistor (PNP) required for current and voltage regulation

To summarize, the battery protection cum charge regulation IC BQ2057 will provide the CCCV charging mode, overvoltage protection and charge recharge threshold. Undervoltage protection is provided by the microcontroller.

4.5 Battery Box

Battery box will be a simple rectangular casing for battery. It will be made of aluminium and insulated from the inside with kapton. Following figure gives an idea of the design.



4.6 Voltage Regulators

The voltage regulator (also known as the power conditioning module) converts the raw battery or solar panel voltage into a regulated voltage for the loads. An industrial grade DC- DC converter will be used considering following factors:

- Output voltage(s) : 3.3V, 3.6V, 5V
- Input voltage range : 5-10 Volts
- Typical and maximum output current
- Switching frequency
- Efficiency (> 85%)
- Output ripple
- Electromagnetic interference(EMI)
- Phase margin (stability)
- Transient response
- Soft start
- StandBy Mode
- Redundancy

The PTH08080W step-down switching regulator and the family REG103 from the Texas Instruments have been selected for this purpose.

4.6.1 PTH08080W

This IC is used for providing regulated power to the various loads of the satellite, namely OBC, Beacon, Downlink, Magnetorquer and GPS. The PTH08080W has the following specifications:

- 4.5-V to 18-V Input Voltage Range
- Wide-Output Voltage Adjust (0.9 V to 5.5 V)
- Efficiencies Up To 93%
- On/Off Inhibit
- Undervoltage Lockout (UVLO)
- Ambient Temperature Range: –40°C to 85°C
- Output Overcurrent Protection (Non-latching, Auto-Reset)
- Over-temperature Protection

The current limits of the modules leave a wide margin with no loss in efficiency. The wide input voltage range covers the entire useful battery voltage range of 6V to 8.4V.The modules can be switched on and off by the power systems microcontroller through the ON/OFF inhibit pin. The industrial temperature range makes the module suitable for our application.

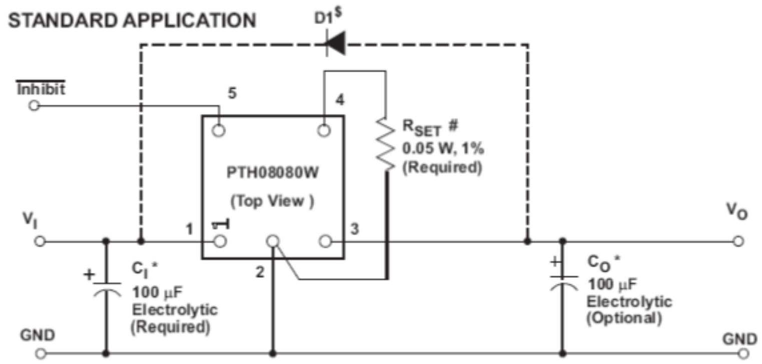


Figure 4.2: Courtesy - Texas Instruments

Aluminum electrolytic capacitors cannot be used at the input and the output as they are not recommended for use below 0°C. Hence, other type of capacitors like OS-CON, poly-aluminum or polymer-tantalum capacitors will be used as recommended in the datasheet. Tantalum capacitors which were used in the prototype circuit, were found to have very low reliability. Hence, CWR06 are chosen for further use. The output voltage is set by the R_{SET} resistor. A 432Ω gives an output voltage of 3.327V.

4.6.2 REG103

ICs from this family are used for providing regulated voltage to the microcontroller (REG103UA-3.3) and the Uplink board (REG103UA-5).

The salient features of these ICs are:

- High Accuracy of ± 2%
- 3.3 and 5 V output versions
- Thermal Protection
- Very Low Noise: 33μVrms
- Operating Temperature Range of -40 to 85 °C
- Operating Input Voltage Range of 2.1 to 15V

4.7 Current Distribution Switches

MOSFET switches of very low internal resistance will be used for power distribution. Considering internal resistance, current capacity and flight heritage, IC TPS203x from Texas Instruments and IC FDC6324L from Fairchild Semiconductors were chosen.

4.7.1 TPS203x

IC TPS203x is used for overcurrent protection for Beacon, OBC, Downlink, Magnetorquer and GPS. It has the following features:

- 33-mΩ internal resistance
- Ambient Temperature Range, –40°C to 85°C
- Short-Circuit and Thermal Protection
- Overcurrent Logic Output
- Operating Range: 2.7 V to 5.5 V
- Logic-Level Enable Input
- Typical Rise Time: 6.1 ms
- Undervoltage Lockout
- Maximum Standby Supply Current: 10 μA
- No Drain-Source Back-Gate Diode

		Min	Max	Unit
Continuous Output Current	TPS2030	0	0.2	A
	TPS2031	0	0.6	

4.7.2 FDC6324L

The FDC6324L is used to protect the magnetometer from overcurrent. The main reason for using this IC instead of TPS203x is the higher input voltage demanded by magnetometer, which is beyond the maximum input voltage of TPS203x. The salient features of this IC are:

- Input Voltage Range: 3-20V
- ON/OFF Voltage Range: 1.5-8V
- Load Current at V_{DROP}: 1.5A

- Operating Temperature Range: -55 to 150°C
- Maximum Power Dissipation = 0.7W

4.8 Microcontroller

The main functions of the microcontroller are as follows:

- The microcontroller turns ON the other circuits a specified amount of time after ejection from the launch vehicle.
- It protects the battery from undervoltage.
- It monitors the load status information (normal/overcurrent) provided by the current limiting switches.
- Readings for health monitoring are conveyed to the OBC every minute
- It turns loads ON or OFF on the command of the OBC.
- Power microcontroller is powered off the battery bus by a separate linear power supply.

Since using space grade microcontrollers is prohibitively expensive, commercial ones will be used. An 8-bit ATmega 32 microcontroller has been chosen to serve the purpose.

The features of the ATmega 32 microcontroller are:

- Advanced RISC Architecture
- 131 Powerful Instructions – Most Single-clock Cycle Execution
- 32Kbytes of In-System Self-programmable Flash program memory
- 1024Bytes EEPROM
- 2Kbytes Internal SRAM
- Interrupt capability
- Power-on Reset and Programmable Brown-out Detection
- 8 channel, 10 bit ADC
- 40 pin PDIP package
- Speed Grade: 0-8MHz
- 32x8 general purpose working registers

4.9 Hardware List

Sr. No	Component	Description	Nos Used
1	Solar Cells	GaAs 18% eff. , 0.87V VMP	165
2	Battery	2S-3P arrangement of 18650 Li-ion cells	1
3	3.3V Regulator	REG103UA-3.3	1
4	5V Regulators	PTH08080W (3.3,3.6, 5V)	4
		REG103UA-5	1
5	Microcontroller	ATmega32	1
6	Power Distribution Switches	TPS203x	5
		FDC6324L	1
7	Battery Protection	BQ2057	1
8	Power-ORing Diodes	MBRS320	7

4.10 Testing of Hardware

4.10.1 Battery Overcharge Protection Testing

Initial Conditions: External Power source connected across Solar Panel connector
V_{BAT} = 7.5V (Before switching on power supply)
V_{CC} = 10.5V
I_{CC} = 1.18A

Observed Charging Curves:

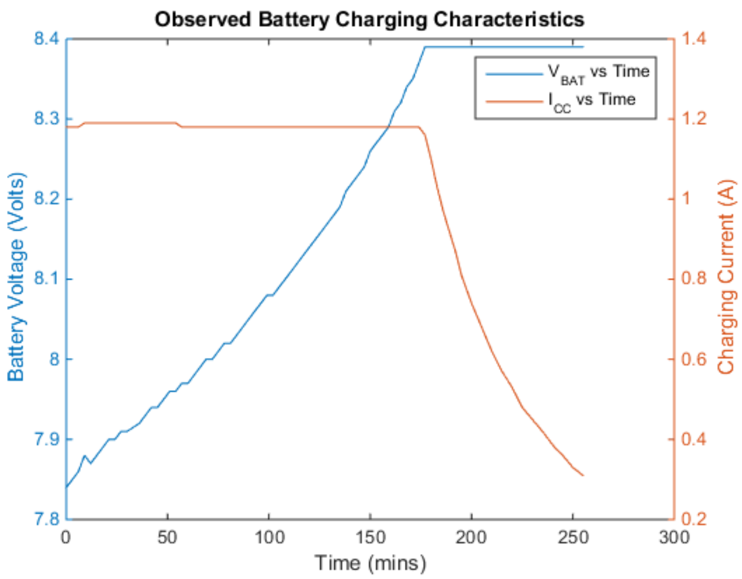


Figure 4.3: I_{CC} vs Time

Final Conditions:
$V_{BAT} = 8.39$V
$V_{CC} = 10.5$V
$I_{CC} = 0.08$A

As can be seen from the plots, the BQ2057 IC effectively prevents overcharging of the battery

4.10.2 Battery Undervoltage Protection Testing

Testing Environment: Fully Charged Battery is connected to the loads through the power board. Microcontroller is programmed to turn of the loads when battery voltage falls below a pre-determined threshold.
Thresholds Tested:
6.6V (Power Saving Mode), 6V (Safe Mode)

Observations:
Loads were turned off as expected.

4.10.3 PTH08080W Testing

Input to each PTH: V_{BAT} - 0.3V (diode drop)
where V_{BAT} is between 6V and 8.39V
Outputs:
5V regulator : 5.0V
3.3 V regulator: 3.28V
3.6V regulator: 3.59V

Inferences: The regulators are providing satisfactory output regulated voltage

4.10.4 TPS Testing

1. **Normal-mode testing:**

Input to TPS of:	**Output of TPS of:**
Beacon: 4.8V (diode drop)	Beacon: 4.8V
Downlink: 4.8V(diode drop)	Downlink: 4.8V
Magnetorquer: 3.3V(diode drop)	Magnetorquer: 3.3V
OBC: 3.29V	OBC: 3.29V
GPS: 5V	GPS: 5V

Inferences: The voltage drop across the TPS is negligible and hence its power consumption is negligible. Thus, the TPS works satisfactorily as a switch

2. **Over-current Testing:**
Testing Environment:

   (a) A potentiometer was used as a load and its resistance was slowly reduced to zero to produce over-current

   (b) A short was connected across the load

   Observations:

   (a) In case (a), the TPS switched to a constant current mode and the voltage tapered off after the current rose above the rated threshold (0.2 A for OBC and 0.6 A for all other loads). After a short time, the Over Current pin of the TPS went low and this generated the signal of overcurrent for the microcontroller to take further action.

   (b) In case (b), the Over Current pin of the TPS went low immediately on turning on the load and this generated the signal of overcurrent for the microcontroller to take further action.

   Inferences: The behaviour of the TPS was expected as per its datasheet. Thus, the TPS works effectively as an over-current protection switch.

Chapter 5

Software

Software for micro-controller is written in embedded C language. A basic framework for the final code has been written and tested. Micro-controller monitors seven loads and communicates with On Board Computer with I2C interface. Two critical currents and three critical voltages are read and saved. Currently, it can accept command through I2C. Accordingly, command is executed and critical quantities and load status data is sent back. The battery voltage is also continuously monitored and suitable actions are performed when it falls below pre-determined thresholds. All loads are also monitored for over-current and the information is sent to the OBC via I2C and the power board itself switches off the OBC in case of over current experienced by the OBC.
Flowchart for the code is attached separately in the appendix

Chapter 6

Health Monitoring

The following quantities are part of the health monitoring data:

1. Load Status - This byte indicates whether a particular load is ON or OFF. It has one bit corresponding to each of the seven loads, Beacon, Downlink, Magnetorquer, Magnetometer, OBC, GPS and Uplink. One bit is unused

2. Panel Current - This byte contains the digital voltage corresponding to the panel current. This digital voltage is provided by the current sense amplifier MAX4372

3. Consumption Current - This byte contains the digital voltage corresponding to the consumption current provided by MAX4372

4. Battery Voltage / 3 - This byte contains the battery voltage divided by three

5. Downlink Voltage / 2 - This byte contains the downlink voltage divided by two

6. OBC Voltage / 2 - This byte contains the OBC voltage divided by two

7. OC Status - This byte indicates whether a particular load is experiencing overcurrent. It has one bit corresponding to each of the five loads, Beacon, Downlink, OBC, Magnetorquer and GPS. Three bits are unused

Thus, the health monitoring data is seven bytes long and is transmitted to the OBC every two seconds

Chapter 7

Emergency Mode and Safe Mode

7.1 Emergency Mode

This mode shall be entered when the battery voltage drops below 6.6V.
All components except the Beacon and the Power board will be switched off by the power board in the following manner:

1. Downlink
2. All control sensors and magnetorquer
3. OBC circuit

7.2 Safe Mode

This mode shall be entered when the battery voltage drops below 6V.
The components will be switched off in the following manner, by the Power board:

1. Beacon
2. Power Circuit(other than Microcontroller)

Chapter 8

SNAP Overview

8.0.1 Introduction

SNAP is the event of the ejection of the satellite from the launch vehicle. The SNAP circuit is required to make sure that the satellite starts operation only after the ejection from the launch vehicle. The RF communication, sensors and actuators are completely off during launch. The micro-controller on only one of the circuit boards (power board) is in sleep mode and hence consumes only 3.26μA (Eq. **??**). All other circuit boards are switched off.

8.0.2 Circuit Diagram

Fig. **??** shows the pin configuration of the SNAP connector on the Power Board. The micro-controller used on the power board is ATmega32.

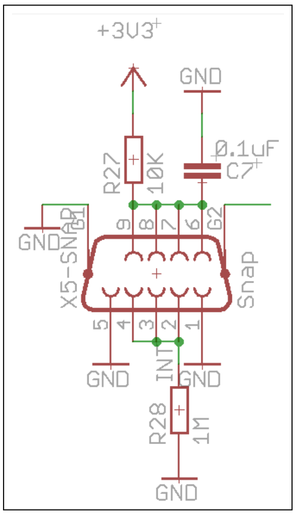
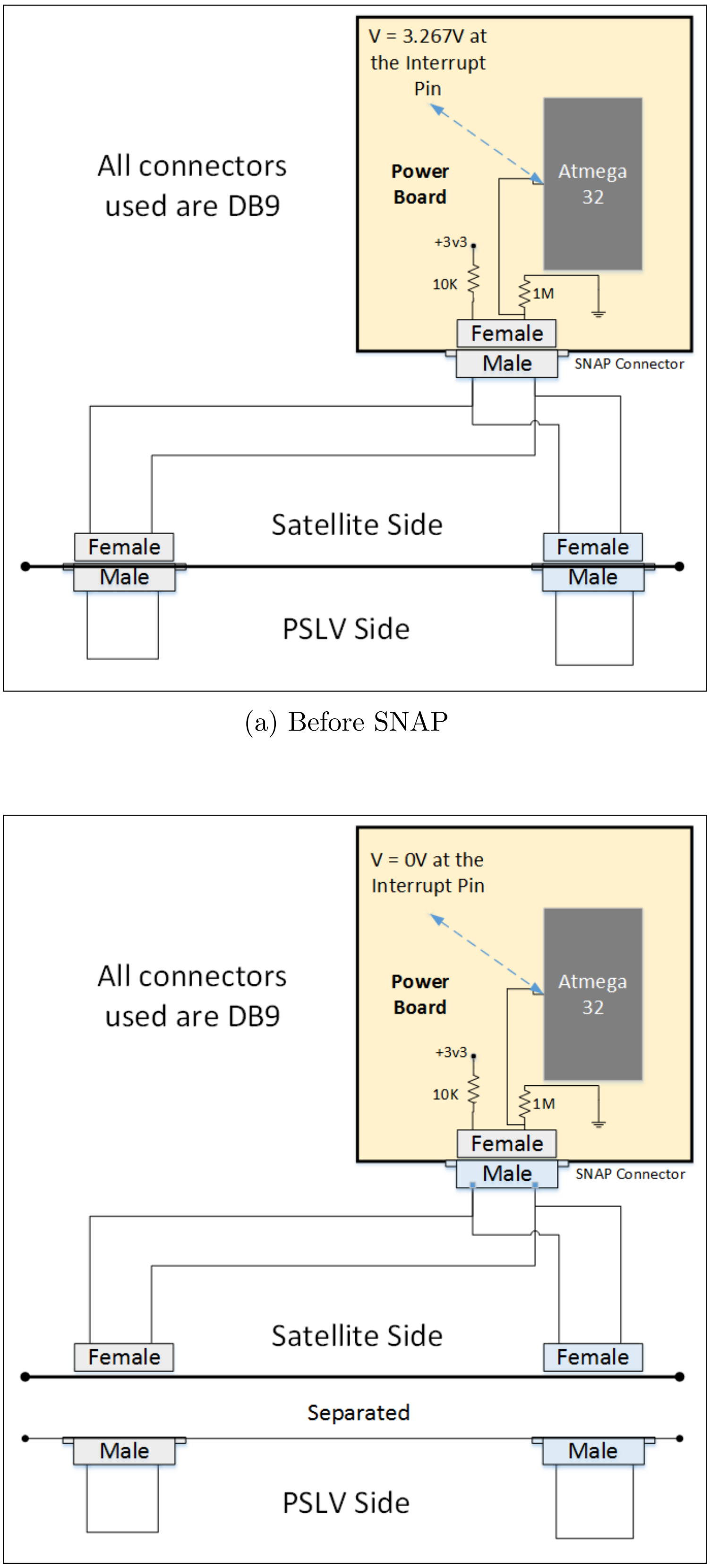


Figure 8.1: Pin Configuration of SNAP Connector on Power Board

An electrical SNAP is used. As can be seen from Fig. **??**, two connectors from the satellite side are connected to the corresponding connectors on the launch vehicle before launch. This establishes a connection between V_{CC} and GND and since the ratio of the resistors used is 1:100, the voltage level at the interrupt pin is close to V_{CC} ($0.99V_{CC}$). After SNAP occurs, the interrupt pin is pulled down to 0V as can be seen in Fig. **??**. LOW at the INT pin for a specified amount of time (few hundreds of microseconds) causes the ATmega to wake up from sleep. Level Triggered Interrupt is used so that the ATmega doesn't wake up in case of any stray noises. Two connectors connected in parallel have been used for redundancy. Hence unless both the connectors are separated, the micro-controller will not wake up.



(a) Before SNAP

(b) After SNAP

Figure 8.2: SNAP Overview

8.0.3 Sequence of Operations after SNAP

Here is the sequence of operations after SNAP takes place:

- Micro-controller of the power board wakes up from sleep and timer is started.
- It waits for 50 minutes so that the satellite moves sufficiently away from the launch vehicle.
- It powers on On-Board Computer (OBC), Beacon and the sensors and actuators.
- Detumbling mode control law begins.

8.0.4 Power Consumption while in SNAP

The current consumed by the SNAP circuit:

$$I = \frac{V}{R} = \frac{3.3}{1010000} = 3.26\mu A \tag{8.1}$$

The power consumed:

$$P = \frac{V^2}{R} = \frac{3.3^2}{1010000} = 0.0107mW \tag{8.2}$$

Total charge drained in 30 days:

$$Q = I * t = 3.26 * 10^{-6} * 3600 * 24 * 30 = 8.44992C = 2.3472mAh \tag{8.3}$$

The total charge capacity of the battery (2S-3P Li-ion battery) is 6600 mAh. Thus, the charge drained before SNAP is negligible (0.036% in 30 days).

8.0.5 Placement of SNAP connectors on the Satellite

Two DB-9 SNAP connectors will come outside the Nadir window and properly routed on the inner side of the FE ring. They are placed oppositely to maintain symmetry. Similar another two DB-9 connectors are placed on AE ring inner side which will be connected to the above two connectors in parallel.

Chapter 9

Provision for Battery Charging through Pre-flight board

For charging the battery in the integrated satellite, a provision has been provided on the preflight board. A connector has been provided on the anti-sun side which is connected to the preflight connector on the OBC board. The preflight board is connected to this connector externally. The OBC-Preflight connector has a PCHARGE pin through which charging voltage can be applied (Figure ??). On the OBC board, the PCHARGE line goes to the OBC-Power connector (Figure ??). and on the power board, this line goes to the battery(Figure ??). On applying the desired voltage to the PCHARGE pin on the preflight board, we can charge the battery.

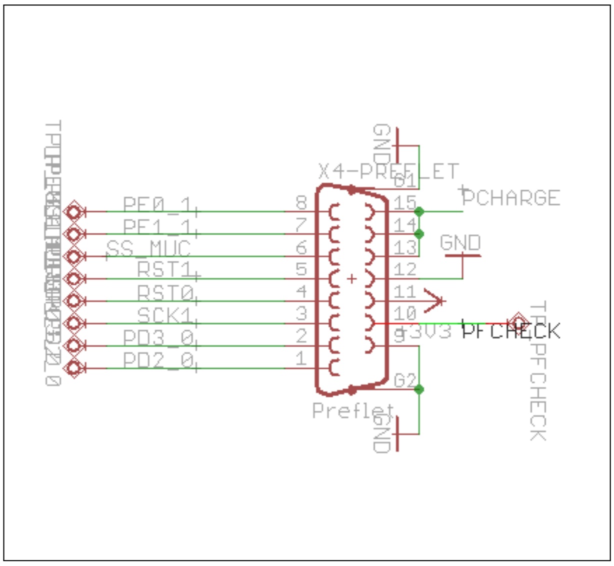


Figure 9.1: Pre-flight connector on OBC

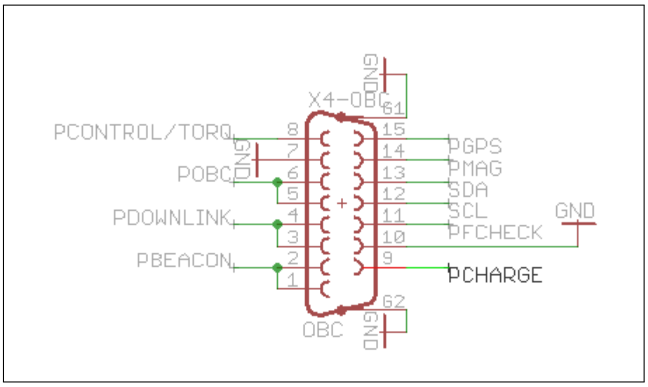


Figure 9.2: Power connector on OBC

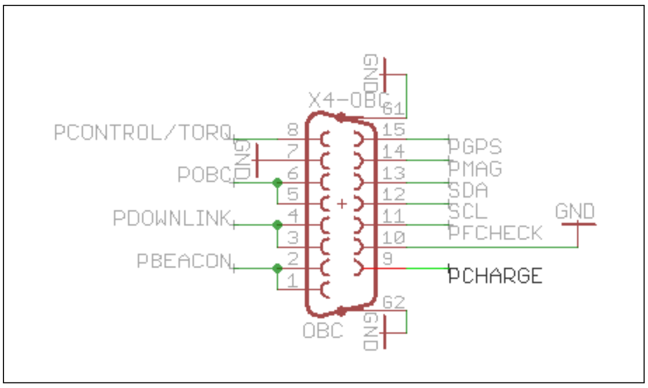


Figure 9.3: OBC connector on power board

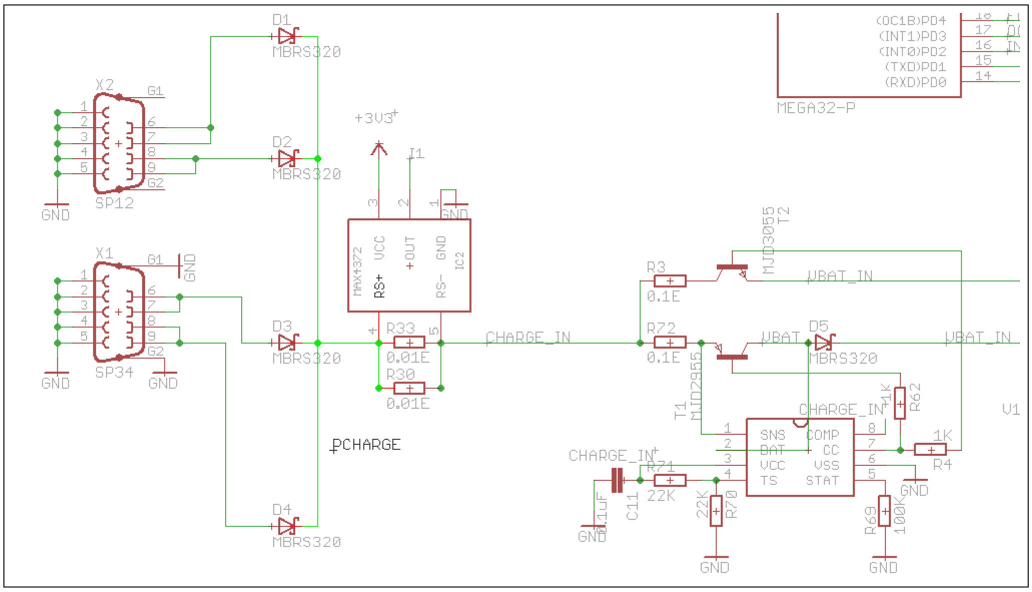


Figure 9.4: PCHARGE line on the power board going to the battery

Chapter 10

Thermo-vacuum Test Results: Power Subsystem Perspective

10.1 SNAP

- Two SNAP connectors were used in parallel for redundancy and the micro-controller woke up from sleep ONLY after both the connectors were removed.
- The micro-controller on the Power board went for a further sleep of 5 minutes after SNAP and the loads were started only after waking up from this sleep. In the flight code, this period will be increased to 50 minutes so that the satellite is sufficiently away from the launch vehicle before starting the loads. This feature was satisfactorily tested.

10.2 Battery Charging and power sharing between Battery and Solar Panels

Testing Environment: An external power source was used to charge the battery. The details of the electrical connections inside the satellite can be found in **??**. Two wires from the DB 50 connector coming out of the chamber were used for charging purposes. The external power source acted as a solar panel, i.e. it was directly connected to the output of the solar panels in the Power Board as can be seen in **??**. Therefore, the Power Board could not distinguish between solar panel and the external power source.

Observations: The following observations were made during the **second thermal cycle**

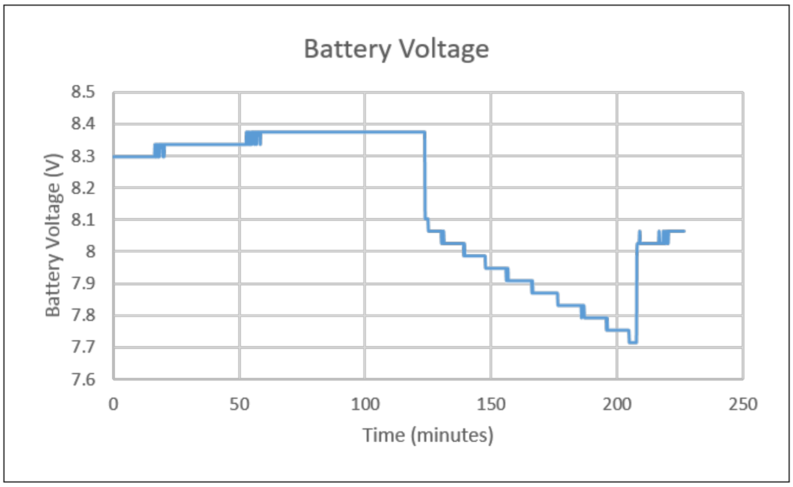


Figure 10.1: Battery Voltage

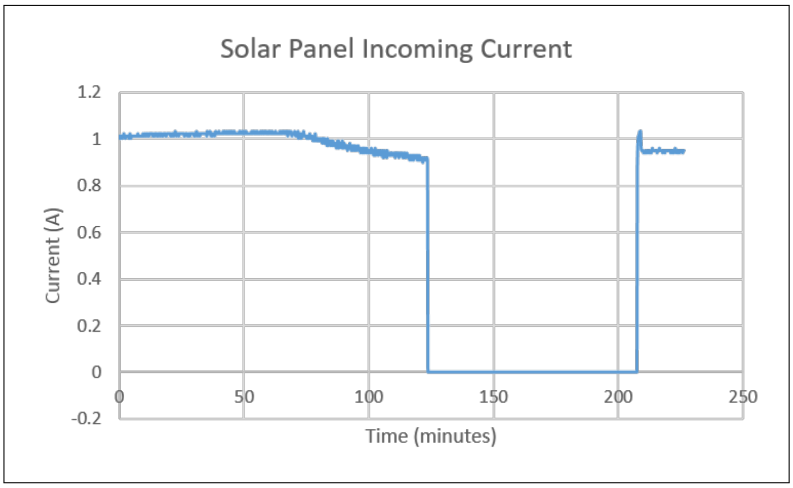


Figure 10.2: Current coming in from the Power Source

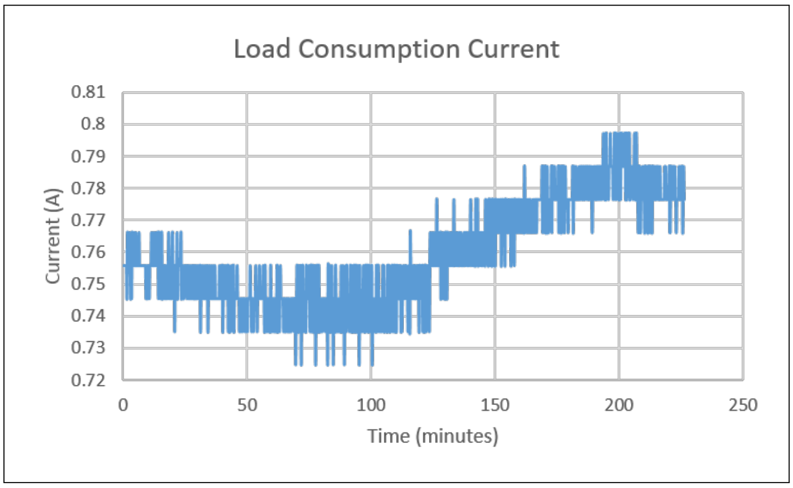


Figure 10.3: Current fed to the loads

Results and Inferences:

- As can be seen from Fig. **??**, the load consumption current is almost a constant with a difference of 0.7 A between minimum and maximum values. Thus the load current requirements can be assumed to be constant.

- As can be seen from Fig. **??** and Fig. **??**, the battery is charged via the Constant Current Constant Voltage mode CC-CV mode, which is essential for charging the Li-ion battery. Initially the charging charge is constant and the battery voltage is increasing and once it reaches the threshold (8.37 V in this case), the battery voltage remains constant, while the charging current gradually tapers off. Thus, the charging of the battery was satisfactorily tested.

- Figures **??** and **??** also show that in the absence of solar power, the battery provides all the power required to drive the loads while if sufficient solar power is present, then all the power required to drive the loads is provided by the solar panels while the surplus is used to charge the battery.

10.3 Power-OBC Communication:

The communication between Power and OBC was verified both ways during the functionality check as follows:

- On externally sending the signal to the OBC to start the downlink, the OBC would command the Power Board to turn ON the downlink board in the immediately next loop. The start of the Downlink transmission indicate that the communication from the OBC to the Power Board was successful and the Power Board faithfully followed the commands.
- On turning ON the downlink, the load consumption current would increase and also the bit corresponding to the Downlink in the LoadStatus byte of the HM data would change from 0 to 1. The increase in load consumption current on turning ON the downlink is shown in Fig. **??**. The observations of these changes on the house-keeping telemetry GUI indicate the successful transmission of HM data from Power to OBC.

10.4 Power-Uplink communication and Reset of the Satellite

- The Power Board checked for the Reset signal in each loop and on receiving the reset signal from the uplink, the micro-controller on the Power Board turned off all the loads for five seconds and then started the required loads again.
- For testing this feature during the thermo-vacuum test, the software of the micro-controller of the Power board was designed such that the board would send all the HM data bytes as '0' on receiving the uplink signal and then reset the satellite.
- Observing '0's on the house-keeping telemetry in the immediately next loop after sending the reset command to the uplink proved and the subsequent delay of 5 seconds in getting the next set of data on the GUI proved that the Power-Uplink communication was working well and that the power board was effectively resetting the satellite on receiving the signal. Also, the returning of the load consumption current after reset to the value when both Downlink and Uplink were OFF (see Fig. **??**) further proves that the Power-Uplink communication and the subsequent reset were successful.

The following profile of the load consumption current was observed during the functionality check in the hot soak:

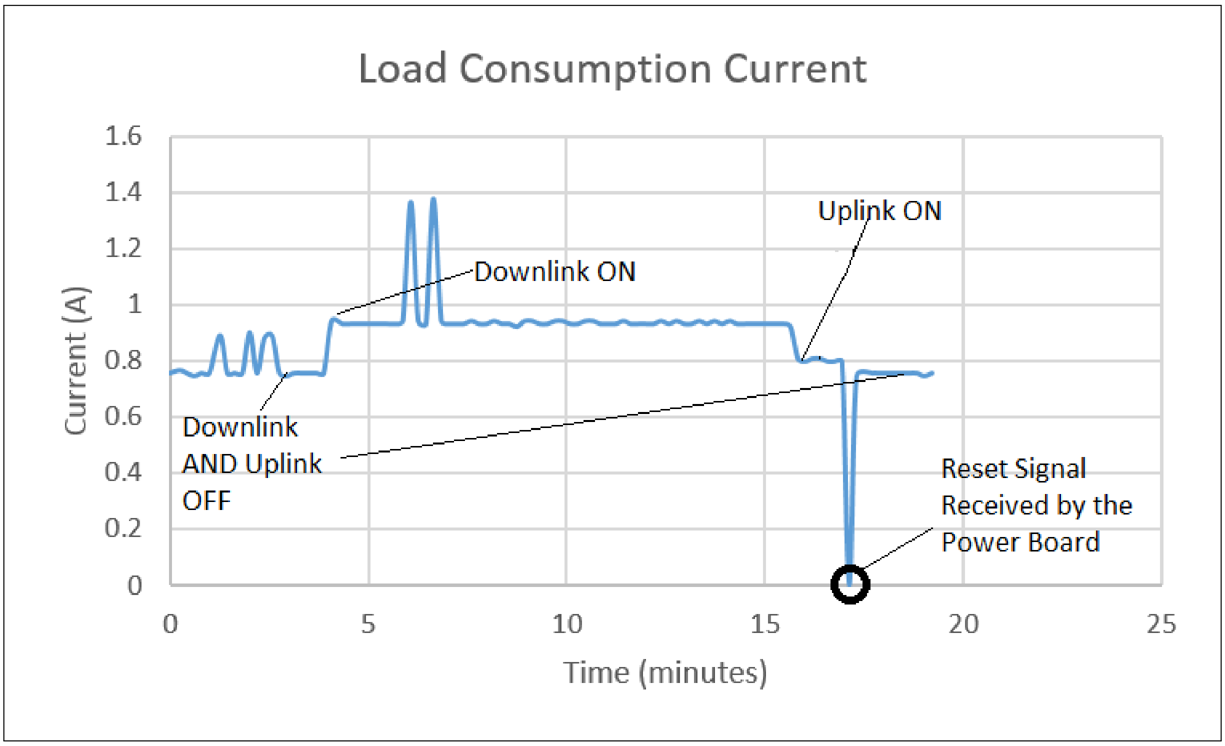


Figure 10.4: Load Consumption Current during Hot Soak

Notes:

- The couple of peaks that are observed in the above profile are due to erroneous data.
- This is not the load consumption current profile for the entire period of the hot soak, but a snippet of the profile.

10.5 Health Monitoring Data:

Data	**Unit**	**Expected Value**	**Observed Value**
Total Solar Panel Incoming Current	Ampere	0 - 1.2	0 - 1
Battery Voltage	Volts	6-8.4	7.5-8.3
Downlink Voltage	Volts	5	5
OBC Voltage	Volts	3.3	3.28
Over current Byte Status	No over current	1	1
	over current	0	
Load Status	Beacon	0: Off/ 1: On	1
	Torquer	0: Off/ 1: On	1
	GPS	0: Off/ 1: On	1
	Downlink	0: Off/ 1: On	Value switching as expected
	OBC	0: Off/ 1: On	1
	Magnetometer	0: Off/ 1: On	1
Load Consumption Current (Ampere)	OBC+Magnetometer +Beacon	approx 0.75*	Case not observed
	OBC+Magnetometer +Beacon+GPS	approx 1.17*	0.75
	OBC+Magnetometer +Beacon +GPS+Downlink	approx 1.77*	1.1
	OBC+Magnetometer +Beacon +GPS+Uplink	approx 1.77*	0.88

Table 10.1: Health Monitoring Data - Expected and Observed Values

* : Absolute maximum values

Inferences:

- All the critical voltages and currents are within the expected range
- Over-current was not observed anywhere
- The Load consumption currents are much lower than expected as the expected values are the absolute maximum values. Beyond these values, overcurrent signal would have been be generated.
- The Power Board updated the HM data every 2 seconds and the updation was observed on the house-keeping telemetry GUI and also in the payload telemetry

Appendices

Appendix A

Flowchart of the Software

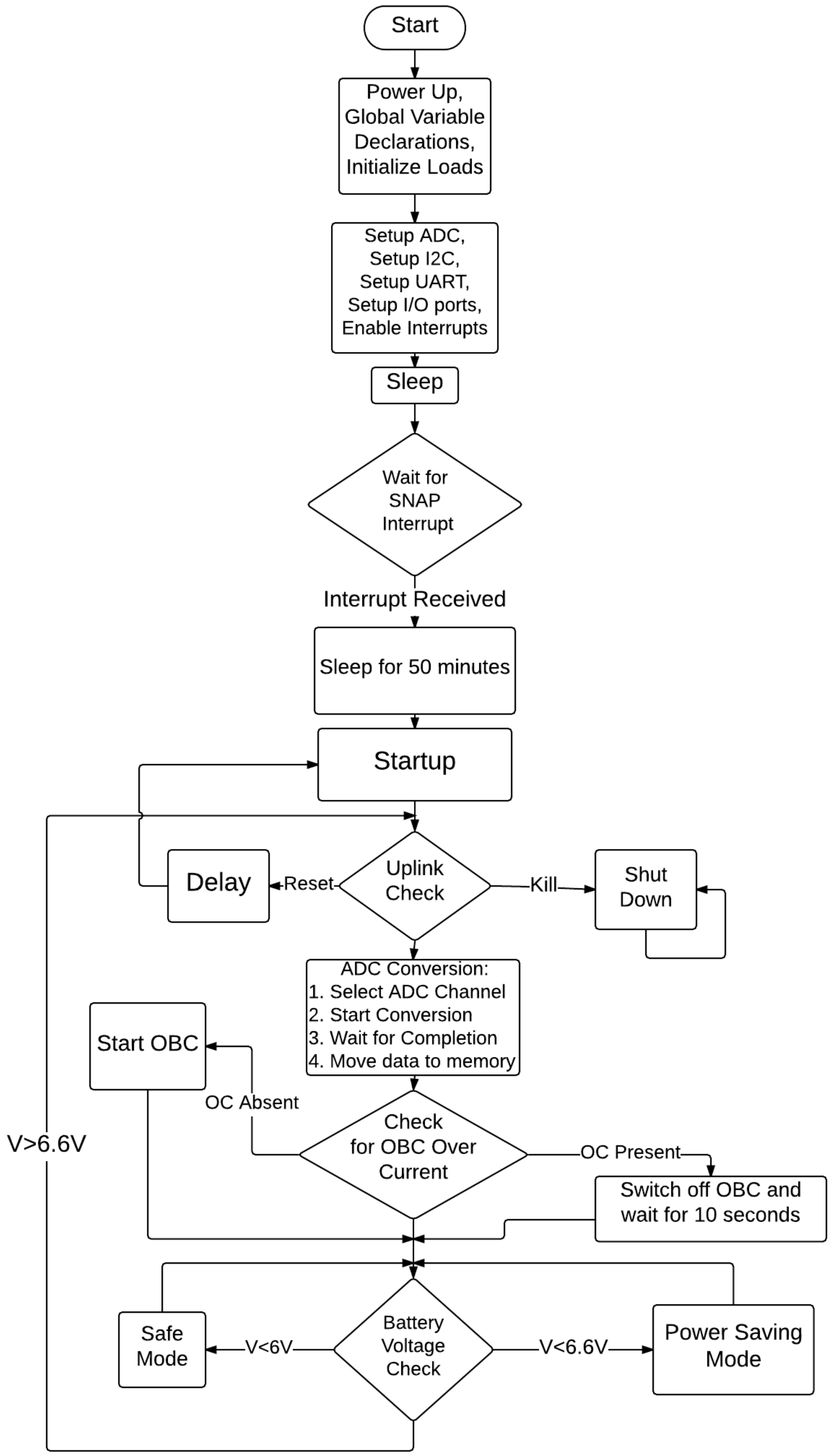


Figure A.1: Main Code Flow Diagram

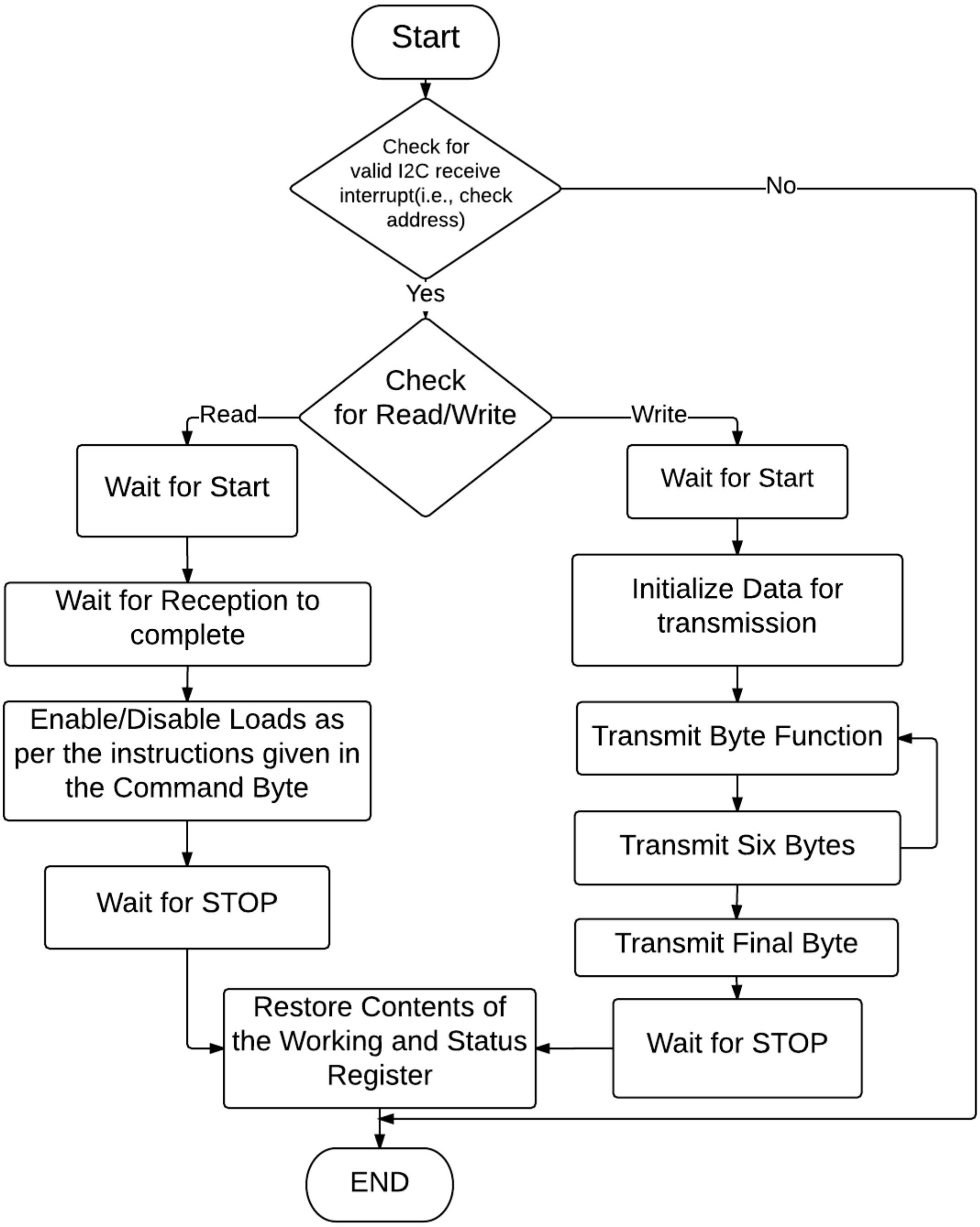


Figure A.2: Power-OBC TWI(I2C) Interrupt Service Routine Flow Diagram