CubeSat and CanSat Development and Demonstration

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This Report Presented in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Computer Science and Engineering

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APPROVAL

This Project/internship titled "**CubeSat and CanSat Development and Demonstration**" submitted by Md Ziaul Haque Zim, ID No: 181-15-11333 to the Department of Computer Science and Engineering, Daffodil International University has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Bachelor of Science in Computer Science and Engineering and approved as to its style and contents. The presentation has been held on 14 September 2022.

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We hereby declare that, this project has been done by us under the supervision of **Dr. Sheak Rashed Haider Noori, Professor & Associate Head, Department of Computer Science and Engineering,** Daffodil International University. We also declare that neither this project nor any part of this project has been submitted elsewhere for award of any degree or diploma.

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ABSTRACT

In modern science, satellites have become a fundamental technique for communication, navigation and exploration of Earth or planets. Most countries are turning to develop their own satellites with their own technology for better communication, navigation and military purposes. Compared to demand in these sectors with lower consistency in research and development, it is essential for the student, engineers and researchers who aspire to contribute to this sector, also interested to know how nano or miniature satellites CubeSat and CanSat are manufactured and operated. The limitation can be overcome by developing CubeSat and CanSat which consists of all the real systems of a space satellite. To earn sufficient knowledge about nano or miniature satellites, CubeSat and CanSat development can be the foundation of learning, facing a lot of challenges and experimental results can be utilized in big satellite development-related projects. This study proposes a complete development, mechanism, design, and assembly of the payload and subsystems to the ground station of CubeSat and CanSat. The CubeSat and CanSat I made have different functionalities. The CubeSat is mainly designed for Earth exploration and observation purpose and have a communication system (CS), Electrical Power System (EPS), Onboard computer system (OBC), Attitude Determination and Control System (ADCS), Antenna, Camera and Payloads. Additionally, different sensors have been used to measure temperature, air pressure, humidity, altitude and battery voltage. After starting up CubeSat automatically established communication to the ground station and start telemetry. The CanSat is a simulation satellite which is developed and designed which have a GPS sensing system for location, a compass sensing system for heading, and radio frequency communication module for ground station communication and different sensing systems to measure temperature, atmospheric pressure, humidity, altitude and battery voltage. Additionally, a drone flight technique approach is also designed and examined known as the ComeBack mission of the CanSat by GPS navigation and it can be returned to the ground station automatically. The main difference between CubeSat and CanSat are extensively studied and discussed. Also, a development process, testing and experimental analysis of both CubeSat and CanSat is presented in this study.

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Introduction

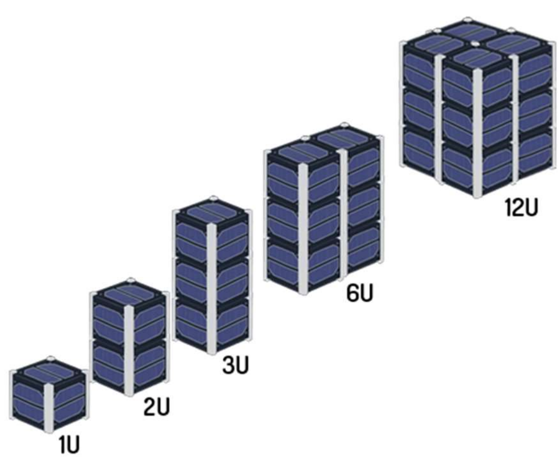
1.1 Introduction

Nanosatellites are very small-shaped and less weighing than 10 kilograms. According to the size, shape and weight, CubeSat and CanSat are categorized as nanosatellites. But simulation of a real satellite-sized, shaped look like a soft drink can is called CanSat. Also, CubeSat is mainly a class of research spacecraft, commonly called nanosatellites.

CubeSats basic design is 10 cm (4-inch) cube, means it dimensions 10x10x10 cm with weight less than 1.33 kg (2.93 lbs.). The ideal CubeSat are 1U in dimensions 10x10x10 cm. But for the complicated mission, CubeSat can be 2U, 3U or 6U. For exploring and interplanetary missions, nanosatellite miniature satellites have been used exclusively in Low Earth Orbit (LEO).

CanSat is mainly used for educational or training purposes. By the name of the can, it looks like a soft drink can and the main challenge of its developer fit all the major subsystems found in a satellite, such as power, sensors and a communication system, into this minimal volume.

The main difference between the CubeSat and CanSat, CubeSat left the atmosphere and orbited the earth in the Low Earth Orbit (LEO) and CanSat never left the atmosphere, nor orbited the earth.



(a) (b)

Figure 1.1: Nanosatellite: (a) CubeSats unit and (b) CanSat

1.2 Motivation

Everyone did not afford millions of dollars to launch a satellite, but still want to carry out scientific investigations in or about the rigours of space. CubeSat has a shape of a little more than Rubik's Cubes. Lower cost of manufacturing can be mass produced more easily, also reduced financial risk for damage or malfunction is reduced as well. Miniature shaped small or nanosatellites are a blessing of advanced scientific and human exploration, reduce the cost of new space missions, and expand access to space. For the lower costs of manufacturing, anyone with a limited budget can able to develop CubeSat or CanSat. Satellite launch costs are rising rapidly day by day and these increasing launch costs are limiting flight opportunities and also decreasing mission funds. Small spacecraft enable simultaneous measurements, constellations and system science observatories. Technology now allows us to fly small spacecraft with capabilities similar to the large.

1.3 Rationale of the Study

CubeSat and CanSat are quite small, main engineering that we have to pack in all of our science tools, wiring and computer processor, plus adding power and communication system for them to wok. The purpose of the CubeSat and CanSat missions was feasibility of using low earth orbit (LEO) for macroscopic plastic waste detection in Earth Oceans. The main differences, CubeSat left the atmosphere and orbited the earth in the Low Earth Orbit (LEO) and CanSat never left the atmosphere, nor orbited the earth.

CubeSat and CanSat both have the standard structure, but designers also trying to improve its physical body. For this type of miniature satellite electronic power management system (EPS) is the most important thing to make the full system alive. Also, choosing of solar panel for the system and integrating it is not that much easy things. Attitude Determinations and Control System (ADCS) is responsible for controlling the full system attitude with the basis of inertia measurement unit (IMU). Also, in CubeSat and CanSat or other miniature satellite all have a common part named On-board Computer System (OBC) which is interact as the brain of the whole system. Flight Computer or shorted as FC is responsible for controlling the full system in flight time and interact as sub-brain of the system. In satellite system communication also a very important. Within communication to the Ground Station (GS) and main satellite system we cannot control or get data from our CubeSat or CanSat system. Payloads are the things what satellite are caring on it. Examples, Cameras, Sensors, Thrusters etc. Navigation System also a thing that is needed to tracking our satellite positions. Antenna also important cause without this important part we cannot send or receive our data. And NASA Operational Simulator for Small Satellites also discussed in this study, that's describe how we can simulate our own satellite in the orbit.

1.4 Research Questions

a. **What would you define a small satellite as?**

With the mass started from 0.1 kg to 500 kg are commonly called as small satellite. These types of miniature satellite are divided into many subsections like, minisatellite, microsatellite, nanosatellite (CubeSat), picosatellite and femto-satellite which are masses less than 500 kg, 100 kg, 10kg, 1 kg and 10 g to 100 g respectively.

b. **Can nanosatellites make a revolutionary change in the field of communication?**

Centering at a relatively fixed point on the Earth (Ground Station) Low Earth Orbit -LEO satellites move at around 7.5 km/s velocity. Generally, most communications satellites are orbiting the Earth in geostationary orbit, 35,900 km (22,300 miles) above the equator. Where geostationary orbit (GEO) satellite is perfectly matched with earth rotation. So, nanosatellite can make a revolutionary change in the field of communication, if we orbit it in geostationary orbit like others communications satellites, because from the earth we found it in a fixed position for communication. Also, we can build a satellite network like Global Positioning Systems (GPS) or Starlink satellite for make a revolutionary change in the field of communication.

c. **Difference between CubeSat and CanSat?**

In the below table some difference between CubeSat and CanSat are given,

TABLE 1.1: Difference between CubeSat and CanSat

No	CubeSat	CanSat
1	Cube shaped miniature satellite.	Can shaped and simulated satellite.
2	CubeSat left the atmosphere.	CanSat never left the atmosphere.
3	Orbited the earth in the Low Earth Orbit	Never orbited the earth.

	(LEO)	
4	CubeSat are launched by rockets.	CanSat are launched by balloon o drones.

d. Why Electrical Power System (EPS) is used for?

For collecting energy from its primary source of energy (solar cells) and distribute the power to the full system. Also used for protecting the other electronics from over voltage flow.

e. Why Attitude Determination and Control System (ADCS) is needed?

Attitude Determination and Control System (ADCS) is taking three-axis data from the inertia measurement unit (IMU) and mainly stabilized Earth-pointing attitude control during mission modes and also control the orbital position.

f. What is GPS attitude determination?

Its one of the many applications where global navigation satellite system (GNSS) can be effectively employed and providing positioning, navigation, and timing (PNT) services on a global or regional basis. GPS attitude determination actually worked by measuring the positions of lots of GNSS antennas mounted on different positions of the aircraft.

1.5 Expected Output

Weather forecasting, radio and television program streaming, navigation and internet satellite are broadly used for earth exploration. CubeSat and CanSat are miniature satellites mainly used by educational or research-based institutes for the development or simulation for practicing whereas big-size satellite development costs a lot. The main purpose of this study is to develop and demonstrate the CubeSat and CanSat. Also, this study discussed about the development process of the different parts of CubeSat and CanSat. After development testing and experimental results were also discussed.

1.6 Report Layout

This report is divided into 16 different sections and discussed specific topics. portrays an idea with yielding as well, our endeavor is to develop and briefly describe the CubeSat and CanSat.

Chapter 1 is introduced about the project.

Chapter 2 describes the background study and basic terminologies of CubeSat and CanSat.

Chapter 3 presents the requirement specification for the development of CubeSat and CanSat.

Chapter 4 talks about the design of CubeSat and CanSat, also describing their 3D modelling, and architectural pats.

Chapter 5 mainly describes the Electrical Power System - EPS, which is responsible for stable power distribution to the full system. This section also talks about Solar Power Management, Battery Management and Power Management units. Also describes the Attitude Determination and Control System - ADCS. With the help of the inertia measurement unit - IMU how is attitude determined and how this system controls the movement of the full system is also described in this section. And talks about the brain of the full system, commonly known as the onboard computer system -OBC, Communication system, explaining about the antennas, which are responsible for establishing communication between satellite.

Chapter 6 talk about the CanSat subsystems.

Chapter 7 describes the ground stations and Chapter 8 depicts the implementation and discusses testing fittingly. 9 talks about the Impact on Society, the Environment and Sustainability and chapter 10 acquiescence's Summary, Conclusion, Recommendation and Implication for Future Research.

CHAPTER 2

Background

2.1 Terminologies

CubeSat is a miniature satellite that is 10 cm per side and weight about 1 kg. These are very simple, versatile, inexpensive and easy to build. CubeSat are used a unique observation capability one that is unmatched in terms of its size. It's also used to test instruments, conduct science experiments, enable commercial applications, support educational projects. CubeSats are launched from a rocket or from the international space station. Like other satellites, they can be flown alone or in a constellation network. Building a CubeSat is the great thing about this innovative approach to exploration. A CubeSat is kind of like a cargo container on a ship. It has a standard size and shape. Similarly with CubeSat it's what's inside those counts. It's up to developer what's he wants to discover. Maybe developer wants to have a weather satellite, measure earth's gravity, or take pictures from space. Maybe developer turns his attention to the moon or solar wind or be on the lookout for incoming asteroids. With CubeSats we get to define our own space adventures.

2.2 Related Works

Interplanetary mission and space observatory program or in orbit system testing miniature satellite are largely used for research purpose. A satellite system in the shape or size of large or tiny, some things are common to them. Attitude determination and control system one among this system. The analysis of the structural shape of micro/nanosatellite flywheels and optimization methods is extensively proposed by the Wei Jiang et al. [1] and in his paper introduce, design and optimized model of flywheel. A magnetorquer is a magnetic device that is commonly used for attitude control, detumbling, and stabilization. This device is creating a magnetic dipole that interfaces with an ambient magnetic field with the uses of electromagnetic coils. Shoaib Ahmed Khan et al. [2] proposed an optimized design and also extensively analyzed the embedded six-layer electromagnetic magnetorquer for 10 × 10 × 30 cm 3-U CubeSat. He also operates thermal analysis and satisfy the feasibility requirements in his study. A simulation model expecting the result of attitude determination algorithm based on multiplicative Kalman filter in presence of GPS system with a MEMS gyroscope and the infra-sensor at Janos Takatsy et al. [3] preprint. With a high computing intelligence, a nanosatellite sent to the 40-kilometer altitude by Ahmed Gaga et al. [4] for the experimenting the weather behavior, atmospheric characteristics and examining the precision of atmosphere measurements. His CubeSat project was developed by a private university named Fez-UPF in the collaboration with KSF agency. In the year of 2021, a fast-moving target tracking system was developed by Zhang Rui et al. [5] and a tracking-by-detection algorithm was proposed by using machine learning approach. They verify their algorithm using the commercial nano remote sensing satellite.

In the year 2021, Shayan Majumder et al. [6] present the dynamic link budget calculation in his paper and also showed a design and development of a communication system for low earth orbit LEO satellites. Shuo Xu et al. [7] broadly discussed about attitude stability of the micro/nano-satellite, also analyzed the environmental disturbance moments, rotational inertia uncertainty and thrust eccentricity moments and lastly perform the numerical simulation. Janos Takatsy et al. [8] again introduce a simulation model for experimenting their attitude determination approach and this study is the part of Cubesats Applied for MEasuring and LOcalising Transients (CAMELOT) mission and including a GPS system equipped, they also demonstrate their attitude determination technique for miniature Low Earth Orbit satellite.

D E Juliando et al. [9] studied low-speed image transfer using LoRa Ra-02 modules.

Orbiting the satellite propulsion system is very important. Roshan Sah et al. [10] designed a propulsion system that is used to deorbit StudSat-2 using the cold gas thruster and studied the structural flow analysis using ANSYS. For the space application hall plasma thruster is very successful now a days and the Plasma Physics Laboratory of the University of Brasília (UnB) present in their article that they got experimental results around 620 W power with above 40 mN force generating thrusters and their new thruster have 1.5 m diameter vacuum chamber where previous one using 0.5 m in diameter and J L Ferreira et al [11] have been tested in most realistic conditions with the 3-U CubeSat structure. The study of Lyubomyr Sabadosh et al. [12] describe the basic of chemical propellant propulsion systems, metal hydride as fuel that can be used for hybrid propulsion system and technical characteristics of nanosatellite

Antennas are important for satellite communication and for miniature satellite it's important to install a good antenna in its sized. UHF printed antenna installed in an 8-U miniature satellite and also good electromagnetics performance also analyzed [13].

Data Processing and data handling is most important for satellite, for that On-board computer systems- OBC are needed in the satellite subsystems. With the 180 MHz clock frequency and 8 MB SDRAM an ARM based processing hardware module is developed that is compatible for CubeSat [14].

Indian Space Research Organization – ISRO developed a 10 kg class versatile Nano Satellite platform that can able to carry 4 kg mass of a payload and also discussed about the optimization on the miniature subsystem and mainframe structure without significant changes change in the bus [15].

University of Tsukuba, Japan developed a nano satellite named "ITF-2" under "YUI project" and Atsushi YASUDA et al. [16] presents the reports of operational results, ultra-small antenna, using of power saving microcontroller with the 2-amateur band radio communication and the achievement of "YUI network".

Intelligent Formation Personal Satellite a miniature nanosatellite was proposed for astronaut assistance and reducing the expensive costs and makes easier the complex scientific studies [17].

In the year 2018, Yuan Fu et al. [18] showed numerical results that digital self-interference cancellation is not necessary when transmission power of ground-satellite uplink is high enough and his study is discussed about the simultaneous transmission and reception (STAR). Also, Cristian Greco et al. [19] investigates the reachability of asteroids and performed sensitivity analysis of thrust level, specific impulse of the engine, uncertainty on the initial mass at launch. Anna Gregorio et al. [20] discussed about the disadvantage of the miniature satellite like they use very low frequency, provides a very limited data ate and preventing the transmission of large amount of data.

Electrical Power System (EPS) is very important subsystem for a satellite. Electrical Power System distribute and monitor a stable power supply to the full system. Naman Vaidya et al. [21] developed a low budget EPS for "Parikshit" nanosatellite including the battery charge regulators, buck converter, over-current protection circuit, battery protection IC's that can able to deliver the demand power of “Parikshit” that is 1.9-3.5 Watts range.

Antenna is the major part of satellite for both receiving and sending signals. With transponders antennas are key to satellite communication. Circularly-polarized microstrip antenna, dual-band in L-Band and S -Band are applied on nanosatellite that orbit in ionosphere for density of electron and measurement of scintillation are discussed extensively by Peberlin Parulian Sitompul et al. [22] .

Navigation is very useful terms nowadays. Planes, ships, spacecrafts and other device widely use navigation system for taking services. As we already know about the nanosatellite and its commonly orbiting in the Low Earth Orbit (LEO). Using the UHF and TT&C communication systems with 3 kg in mass, 10 W power demand and 2.7 years lifetime a nanosatellite proposed for Regional Navigation Satellite System in lower cost compare to current navigation system by L Fathurrohim et al. [23]

2.3 Comparative Analysis and Summary

The systems of CubeSat and CanSat is quite different and flexible in this era if I analyzing with other related work on it. Normally, a CubeSat or CanSat subsystems are divided into many parts, like Electronics Power Systems, Communications Systems, Antenna Systems, On-board computer systems, Flight Computer and Software systems, Camera, Batteries and other sensors. With having different subsystems, I can say that every system has the capabilities to compete with previous systems. In the below a comparative analysis has been shown,

TABLE 2.1: Comparative Analysis with Previous Studies

Year	Ref	Author Name	Contribution		My model	
			Area	Method	Name	Description
2022	[1]	Jiang Wei and Xie W	Flywheel	Design and optimization	Reaction wheel	2 BLDC motor with wheel has been used in X-Axis and Y-Axis to control.
	[2]	Shoaib Ahmed Khan and	Electromagnetic magnetorquer	6 layers embedded electromagnetic	Reaction wheel	2 BLDC motor with wheel has been used in X-

		Anwar Ali		torquer for 3U		Axis and Y-Axis to control.
	[3]	Janos Takatsy and Tamas Bozoki	Attitude Determination and Control System (ADCS)	GPS System, MEMS Gyro and Infra sensor	Attitude Determination and Control System (ADCS)	ADXL 345 and MPU6050 integrated inertia measurement unit (IMU)
	[4]	Ahmed Gaga and Omar Dioui	Atmospheric Sensor System	Sensor based data stimulation		
	[8]	Janos Takatsy and Bozóki	Attitude Determination and Control System (ADCS)	Simulation	Attitude Determination and Control System (ADCS)	ADXL 345 and MPU6050 integrated inertia measurement unit (IMU)
2021	[5]	Zhang Rui and Zhang Xueyang	Asteroid Tracking	Machine Learning	Camera	Birds Eye view Erath observation
	[6]	Shayan Majumder and Hrishit Tambi	Communication System		Communication System	Communication Transceiver SX1278 LoRa Ra-02
	[7]	Shuo Xu and Zhengliang Lu	Attitude Determination and Control System (ADCS)	Numerical simulation to study disturbance moments, rotational inertia uncertainty and thrust eccentricity moments	Attitude Determination and Control System (ADCS)	ADXL 345 and MPU6050 integrated inertia measurement unit (IMU)
	[9]	D E Juliando	Communication System	Low-speed transmission	Communication System	Communication Transceiver

		and R G Putra		using LoRa Ra-02 module		SX1278 LoRa Ra-02
	[10]	Roshan Sah and Prabin Sherpaili	Propulsion and Thruster	Simulation using ANSYS		
2020	[13]	Vieira J. M. and Facco R.	Communication System	UHF antenna fabricated on PCB and installed on 8-U CubeSat	Communication System	Communication Transceiver SX1278 LoRa Ra-02
	[14]	Stacul, A. and Pastafiglia, D.	On-board Computer System (OBC)	ARM based 180 MHz MCU with 8MB SDRAM embedded OBC developed	On-board Computer System (OBC)	Raspberry PI Zero
	[15]	Dubey Mayank & Kader	CubeSat Structure	Fabricated Structure	CubeSat Structure	3D Fabricated Structure
2019	[11]	J L Ferreira and A A Martins	Propulsion and Thruster	Hall Plasma thruster tested with 3-U CubeSat	Reaction wheel	2 BLDC motor with wheel has been used in X-Axis and Y-Axis to control.
	[16]	Atsushi YASUDA and Akihiro NAGATA	Communication System	2-amateur band communication, power saving microcontroller	Communication System	Communication Transceiver SX1278 LoRa Ra-02
2018	[12]	Lyubomyr Sabadosh	Propulsion and Thruster	Metal hydride fuel for hybrid propulsion	Reaction wheel	2 BLDC motor with wheel has been used in X-Axis and Y-Axis to control.
	[17]	Yasuda and Nagata	CubeSat	Full CubeSat system for assistant	CubeSat Structure	3D Fabricated Structure
	[18]	Yuan Fu	Communication	simultaneous	Communication	Communication

			System	transmission and reception (STAR)	System	Transceiver SX1278 LoRa Ra-02
	[19]	Cristian Greco and Di Carlo	Propulsion and Thruster		Reaction wheel	2 BLDC motor with wheel has been used in X-Axis and Y-Axis to control.
	[20]	Anna Gregorio and Cuttin	Communication System	Improving transmission frequency and	Communication System	Communication Transceiver SX1278 LoRa Ra-02
	[21]	Naman Vaidya and	Electrical Power System EPS	Power management and distribution	Electrical Power System EPS	Power management and distribution
	[22]	Peberlin Parulian Sitompul and Sumantyo	Antenna	L-Band and S-Band circularly polarized microstrip antenna	Communication System	Spring Antenna for SX1278 LoRa Ra-02
	[23]	L Fathurrohim and Poetro	Navigation and Communication System	UHF and TT&C with Regional Navigation Satellite System	GPS Sensor	NEO 6M

2.4 Scope of the Problem

The CubeSat and CanSat or miniature satellite system is the scope in this era to solve many problems related to earth exploration, observations, navigation and weather updates.

CubeSats are basically nanosatellites in the shape of cubes 10x10x10 cm. This type of satellite mass is less than 10 kg and orbits in low Earth orbit (LEO). The development costs of this type of satellite are very budget-friendly so educational or research-based institutes afford this easily.

CanSat is also the type of miniature satellite commonly available in the shape of a soft drink can. This type of satellite is basically designed and developed for simulation purposes and they never leave the Earth's atmosphere or never orbit.

2.5 Challenges

The main challenges are to develop the CubeSat and CanSat embedded hardware systems. Also, ensuring both hardware and software are simultaneously progressing and monitoring the mission tasks for operating 24-hour, automated ground operation system to be developed to maintain low manpower requirement.

CHAPTER 3

Requirement Specification

3.1 Introduction

This chapter describes the full specification of hardware and software, also their descriptions of how the expected CubeSat and CanSat systems will perform. For effective utilization of the subsystem development good and standardized equipment should use. CubeSat and CanSat have several hardware subsystems named Electrical Power System (EPS), Attitude Determination and Control System (ADCS), Onboard computer system (OBC), Payloads, Communication systems and Antennas. Basically, all of these subsystems are parts of embedded system and in combination of these subsystem build the complete system.

3.2 CubeSat Block Diagram

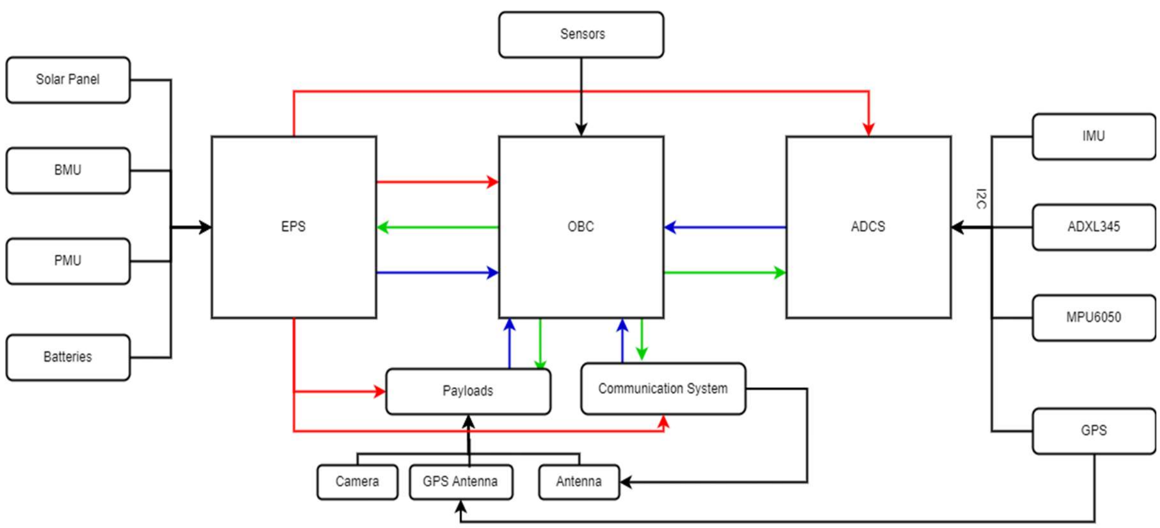


Figure 3.1: CubeSat Block Diagram

As we can see that firstly, our CubeSat system is divided into 3 major parts named EPS or Electrical Power System, OBC or On-board Computer System and ADCS or Attitude Determination and Control System. These major systems have auxiliary subsystems including sensors, modules, antennas and payloads. With the combinations of these additional subsystems, the full system works.

EPS or Electrical Power System is responsible to distribute stable power supply to the full system. It's had some auxiliary embedded sub units named BMU or Battery Management Unit, PMU or Power Management Unit, Solar Panels and Batteries.

OBC or On-board Computer System works as the brain of the system. The main operations of OBC are data and command handling, processing, and responding.

ADCS or Attitude Determination and Control System works as the controller of the system. ADCS helps to detect the position of the physical system by using an inertia measurement unit (IMU).

3.3 CubeSat Flowchart Diagram

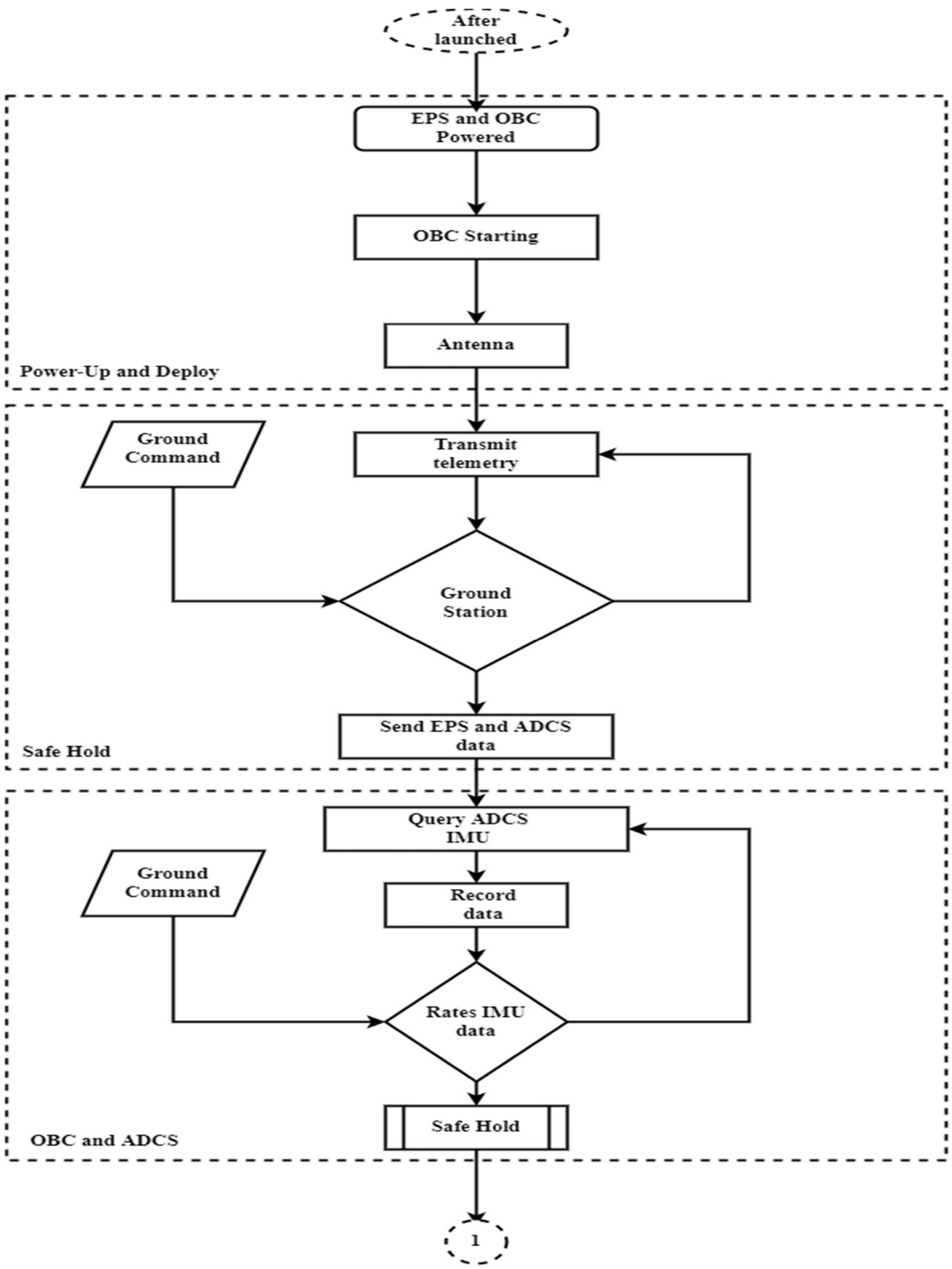


Figure 3.2: CubeSat Flowchart Diagram of Phase I

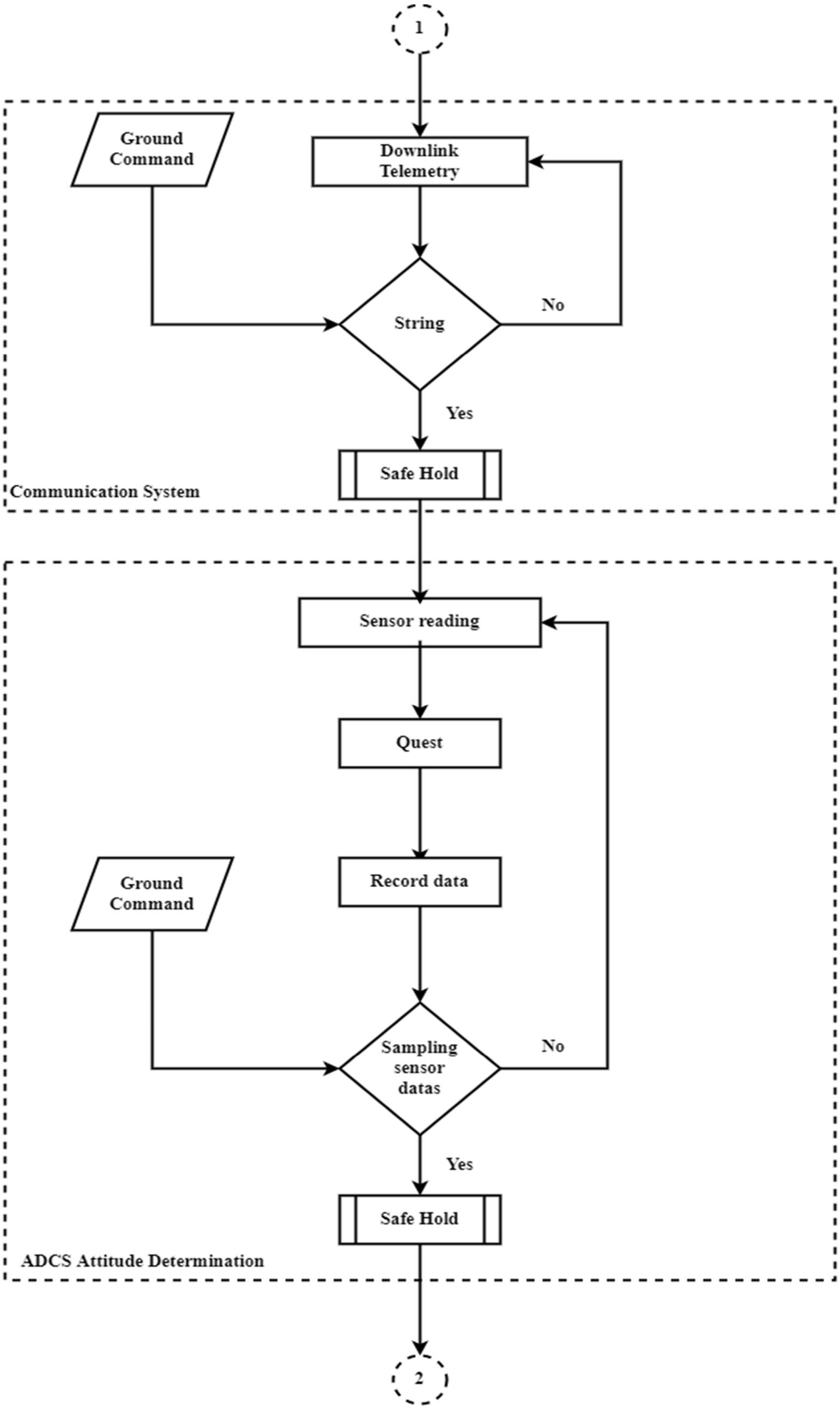


Figure 3.3: CubeSat Flowchart Diagram of Phase II

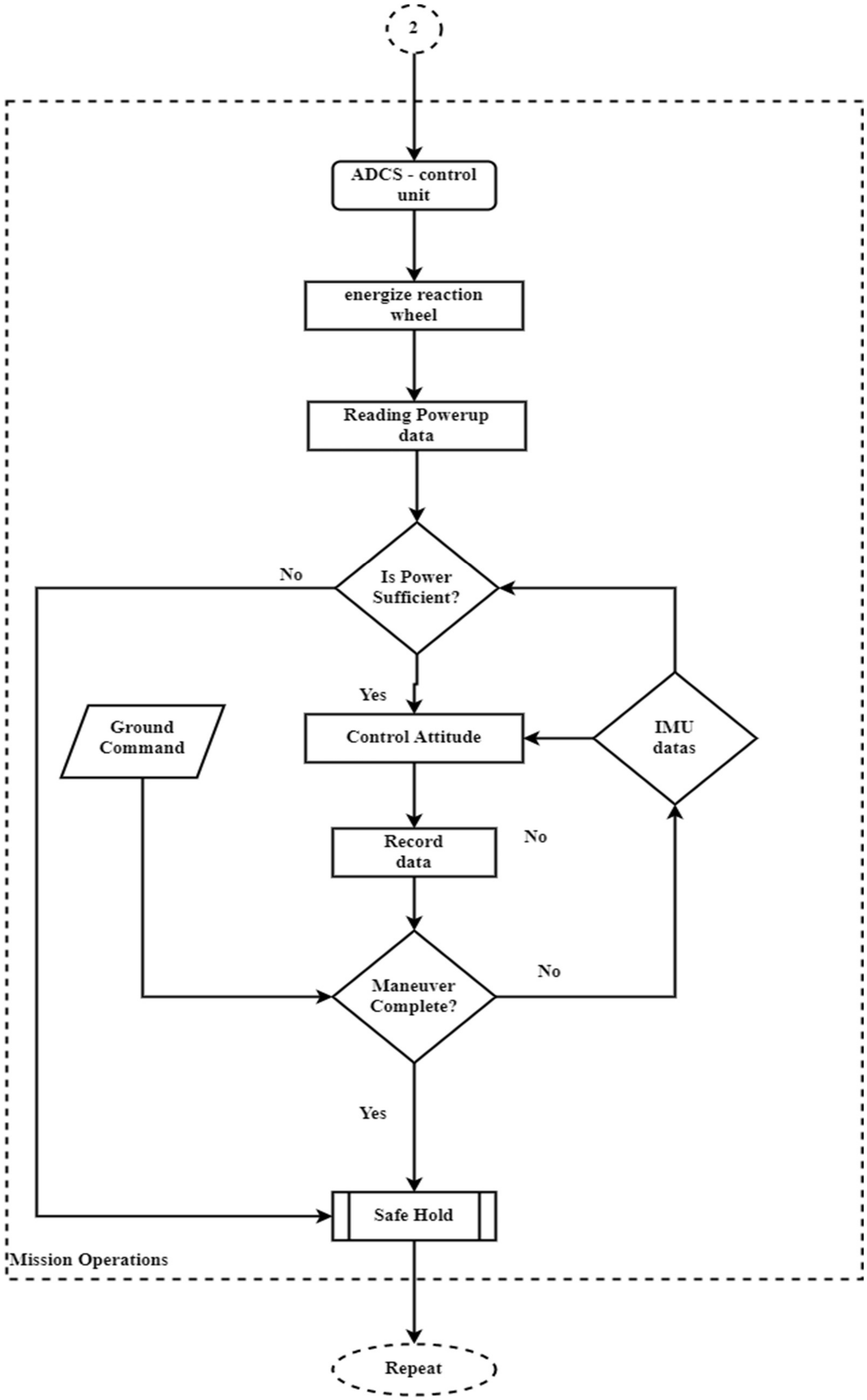


Figure 3.4: CubeSat Flowchart Diagram of Phase III

3.4 CanSat Block Diagram

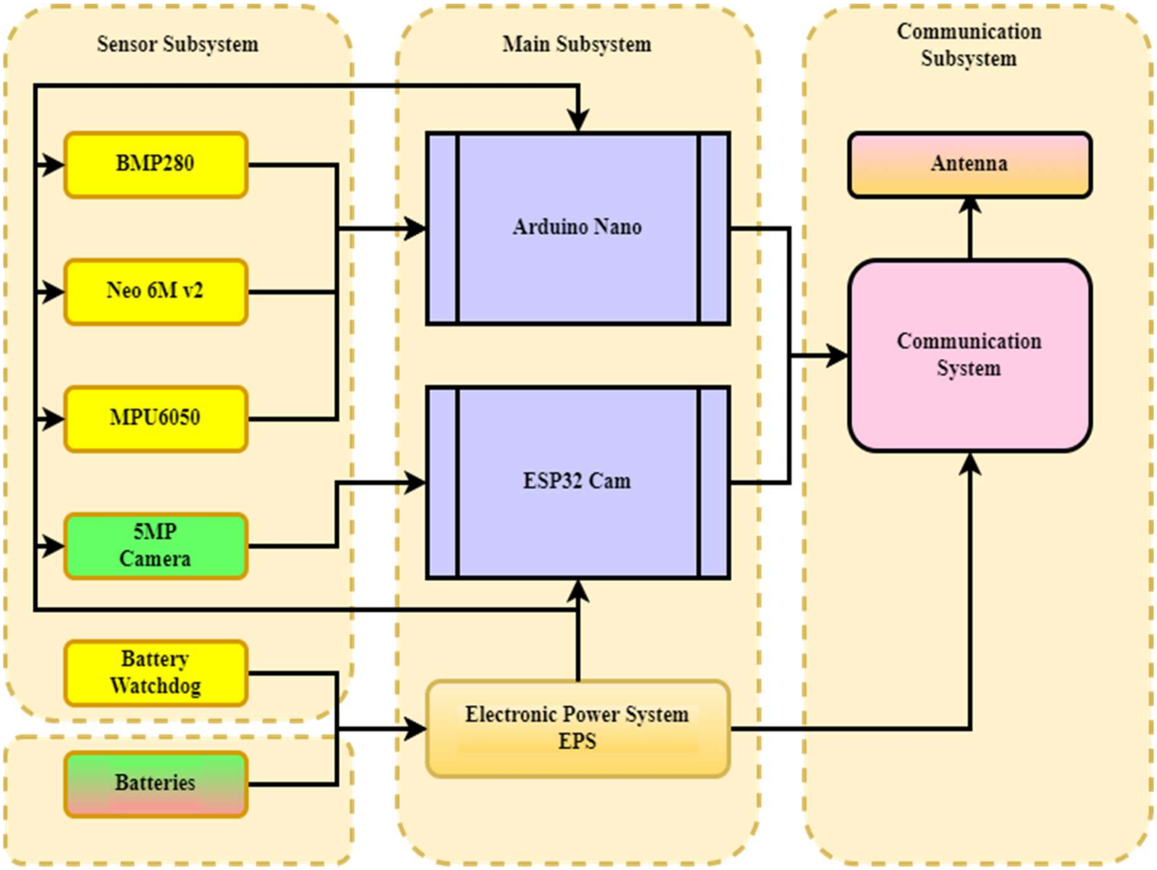


Figure 3.5: CanSat block diagram

As I discussed before, CanSat are physically can shaped, used for mainly satellite simulation and mostly educational purposes. CanSat never left the atmosphere and never orbited the earth. CanSat are launched by balloon o drones.

Here, in the above diagram we can see the CanSat architecture. CanSat system divided into 3 subsystems. Which are Sensor, Main and Communication systems. Sensor subsystem equipped with sensors for collecting data from the interesting source to electric data signal. BMP280 is responsible for measuring and collecting the atmospheric pressure, Neo 6M v2 is for GPS navigation and MPU6050 is an inertia measurement unit (IMU) for CanSat attitude determination and attitude control.

Can be found by comparing with CubeSat, CanSat system is not that complex. CanSat Electrical Power System (EPS) is very simple that will distribute power to all subsystems and a signal is sent to the ground station if battery power is low. Also, its communication system is basically an nRF24L01 module for transmitting data and receiving commands from the ground station. It's a single-chip radio transceiver for the worldwide 2.4 - 2.5 GHz ISM band with an antenna including RFX2401C IC which is the PA (Power Amplifier) and LNA (Low-Noise Amplifier).

3.5 CanSat Flowchart Diagram

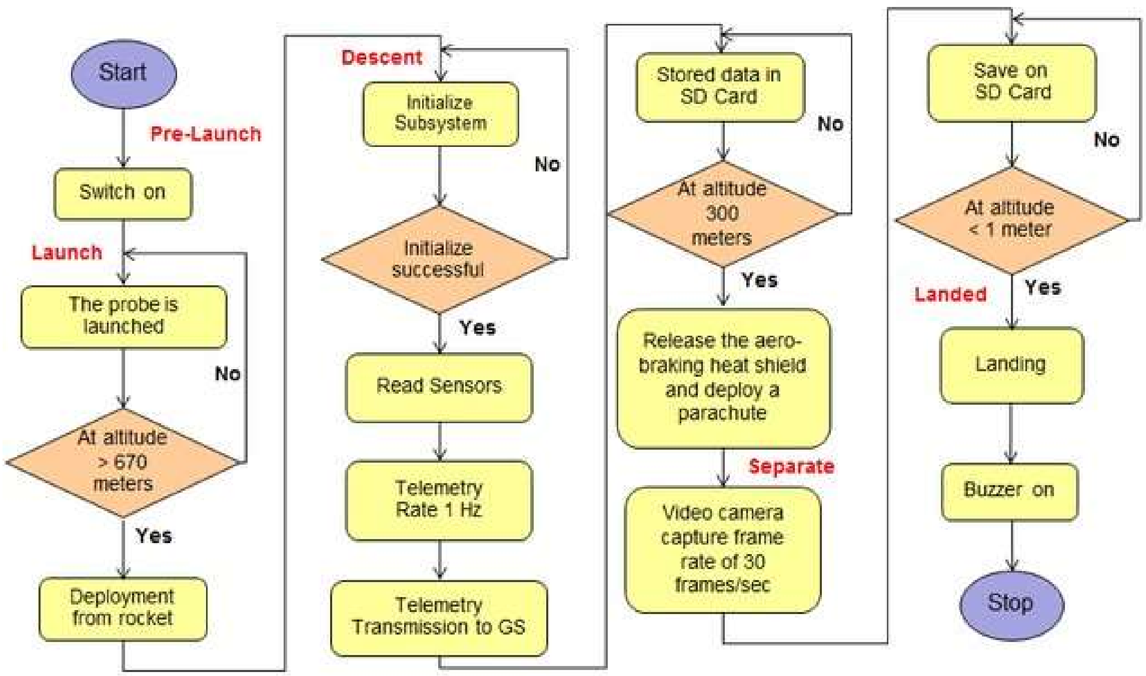


Figure 3.6: CanSat flowchart diagram

In above diagram describe about the CanSat operational flow. CanSat never left the atmosphere and never orbited the earth. CanSat are launched by balloon o drones.

In the Pre-Launch, CanSat system are turned on and ready for launching. After gaining at predefined altitude (initially "greater than 670 meters" in defined) CanSat deployed from the launch vehicle, it can be a rocket, gas balloon or drone.

After completing this phase, CanSat initialize its all subsystems. If initialization is successful then it going to take reads from the sensor subsystems and start transmitting the telemetry to the ground station. Also, it stores data in SD card.

When it comes at 300 meters altitude it deploys a parachute or drone wings, start streaming video with 30 frames/seconds and stores in the SD cards.

At less than 1 meter altitude, the system understand that CanSat is landed in ground and turns it buzzer on giving alarm. After that CanSat can be turned of after a successful operation.

3.6 Working Process of system

In above sections 3.2 and 3.4, CubeSat and CanSat block diagram describes their operational process respectively. Whereas, CubeSat is built for the orbiting the Earth and CanSat are never leave the earth atmosphere or nor orbiting the Earth, its only launched inside the Earth atmosphere and gathers data like atmosphere pressure, temperature, vibration and so on.

According to their operational environments, their working process is not same. In the below table describes the CubeSat and CanSat working process step by step.

TABLE 3.1: CubeSat and CanSat working process

Steps	CubeSat	CanSat
1.	Mission Planning and Pre-launch	Mission Planning and Pre-launch
2.	Launch through a rocket to the Low Earth Orbit (LEO) or above	Launch through a rocket, gas balloon or drones to the Earth atmosphere.
3.	Separate from the rocket and checking	Separate from the rocket, gas balloon or drones and fall due to gravity
4.	Orbit maneuvering to initial proximity distance	Initialize all its subsystems and start telemetry to the ground station.
5.	Opening its Solar Panel and Antennas	Checking altitude and give sensors feed
6.	Initialize all its subsystems, EPS, OBC, ADCS, Communication System and other sensors.	Grounded and mission complete
7.	ADCS start inertia measurement unit (IMU) and walking to the safety eclipse.	
8.	Initialize the Antenna and searching for Ground Station.	
9.	Establishing the communication with ground station	
10.	Sending EPS data, battery health, solar panel health, sensors data and pictures to the ground station	
11.	Continue orbiting the Earth and start mission operations.	
12.	After a time, interval, Ground Station continues receiving the data.	

3.7 Hardware Requirement

To get a more effective utilization of the CubeSat and CanSat development, hardware is the most important thing. Because the lifetime depends on systems hardware. Top to bottom of a CubeSat or CanSat development, hardware is the only physical noticeable parts.

In the developments of Electrical Power System (EPS), Attitude Determination and Control System (ADCS), On-board Computer System (OBC), Communication System and others subsystems needs different types of sensors and modules, ICs, Capacitors, Resistors, Inductors, Diodes, Voltage regulators and etc. electrical equipment's.

3.8 Hardware Component Lists

This section will describe our initial project hardware for clearing the internal devices which have been developed. In the below table shows the component lists and its uses in the project.

TABLE 3.2: CubeSat Hardware Component Lists

CubeSat			
Subsystem	No	Component	Used
Electrical Power System (EPS)	1	Solar Cell	To convert the energy of light directly into electricity
	2	Battery	18650 Lithium for storing the Charge
	3	TP4056	Lithium Battery Charging Processor
	4	DW01A	Lithium Battery Protection IC
	5	8205A	Dual Power MOSFET Battery Disconnect switch
	6	ATMega 328p MCU	Power Management microcontroller to monitor the EPS
	7	Capacitor, Resistors, Diodes	Some mandatory items for building EPS systems
	8	7805	5v voltage regulator IC
	9	AMS1117 3.3v	3.3v voltage regulator IC
ADCS	1	ADXL 345	3-Axis Accelerometer
	2	MPU6050	3-Axis Accelerometer and 3-Axis Gyroscope

	3	STM32F411	Microcontroller for Inertia Measurement Unit (IMU)
	4	ESP 10A	10Amp Electronic Speed Controller
	5	Brushless motor	Brushless Motor for reaction wheel
Onboard Computer System (OBC)	1	BCM2835	Broadcom 1GHz Processor (Single-core) Dual Core Video Core IV GPU
	2	512mb RAM	Random Access Memory
	3	CSI camera connector	For connecting external camera
	4	SD Card connector	For holding operating system
Communication System	1	LoRa Ra-02	SX1278 wireless transceiver
	2	SMT antenna adapter	Connection to the antenna

TABLE 3.3: CanSat Hardware Component Lists

CanSat		
No	Component	Used
1	Arduino Nano	Worked as a brain of the System
2	DHT11	Humidity and Temperature Sensor
3	BMP280	Air Pressure and Altitude Sensor
4	Neo 6M	GPS Sensor for location
5	MPU6050	For inertia measurement unit (IMU)
6	SW-420	High sensitivity non-directional vibration sensor
7	Voltage Sensor	Consisting of two resistors with resistances of 30KΩ and 7.5KΩ
8	Batteries	18650 Lithium-ion batteries
9	Flight controller	Omnibus F4 flight controller
10	Brushless motors	Drone rotor using for stable landing

3.10 Software Requirement

In this study, CubeSat and CanSat have they're on Firmware. It's a low-level software that's operate between hardware and the operating system whereas software runs at the top of the system. Because of hardware project generally I need a software that used to control hardware devices and other peripherals that is connected to the devices.

For Firmware development I write codes in "Embedded C" using KEIL IDE and also used Arduino IDE for minimal development. Also, MATLAB is used for the computational analysis.

Also, Multiphysics software Ansys used to simulate CubeSat physical model and tested with modal and structural analysis and testing result also discussed.

3.11 Conclusion

To play a vital role in developing new technology needs to work with hardware and software. These both are very important because ones need other to tell what to do and others also needs the first one in order to act out its directions. In combination of hardware and software embedded system are builds. In this study I proposed hardware system the CubeSat and the CanSat which have independent hardware system and also some software parts.

CHAPTER 4

Structure Design Specification

4.1 Introduction

The CubeSat and the CanSat or any other miniature or nanosatellite have their own physical structure. To develop a satellite, it's mandatory to study its stability, strength and rigidity of structures. The methodical investigation of the CubeSat and CanSat is described in this chapter. Adobe Fusion 360 software is used to make 3D model design and Ansys is used to simulate physical model and tested with modal and structural analysis.

Figure 4.1: CubeSat Aluminum Structure

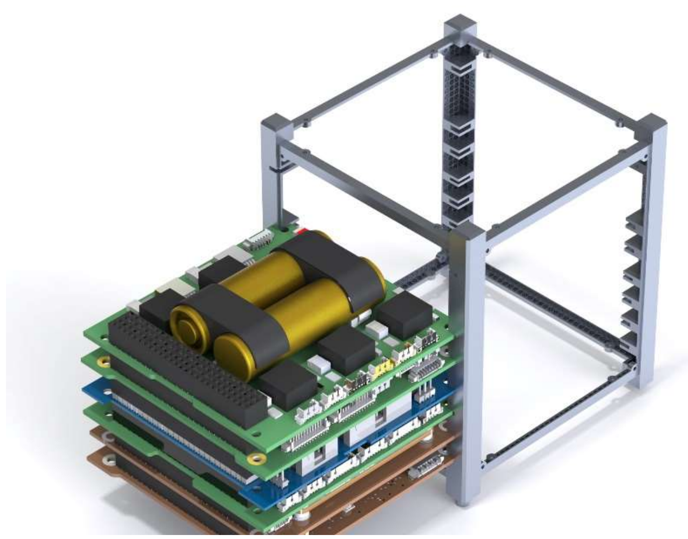


Figure 4.2: CubeSat Structure and Subsystems

4.2 CubeSat 3D Model

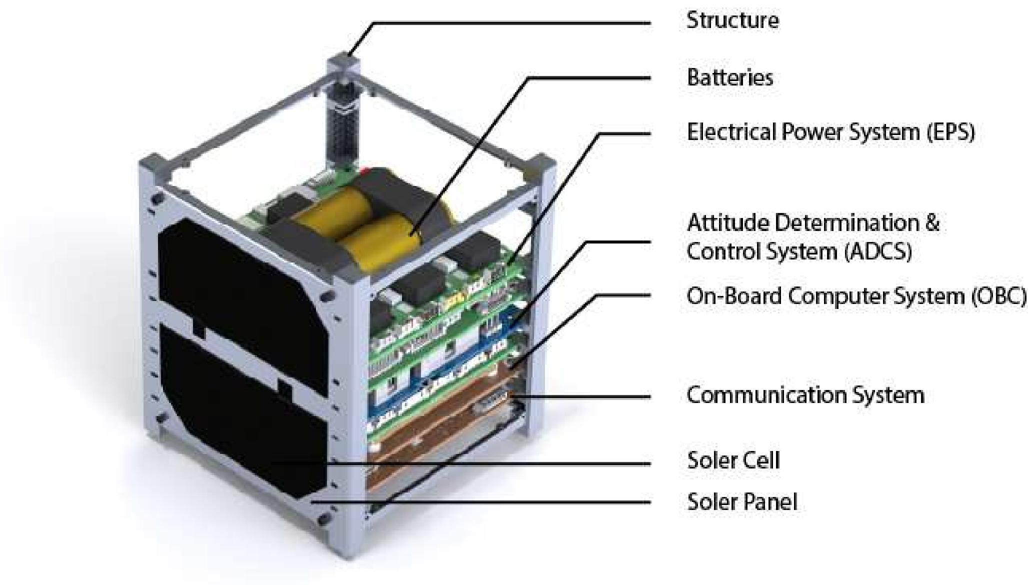


Figure 4.3: CubeSat 3D Model

In the above Figure 4.1, a 3D model of 1U CubeSat has been shown, which gives us a crystal-clear idea about a CubeSat physical structure. In reality, CubeSat is generally covered with solar panels to gather energy, but for better understanding and to give a good idea of also inside view of a CubeSat in the above picture I opened up the other 4 sides.

Mostly CubeSat structure is made by Aluminum 7075-T6 or Aluminum 6061-T6. For experimental purposes my CubeSat model is also printed via a Creality CR-10 3D Printer with ABS filament. In the below Figure 4.2 a 3D printed 1U CubeSat structure has been shown.

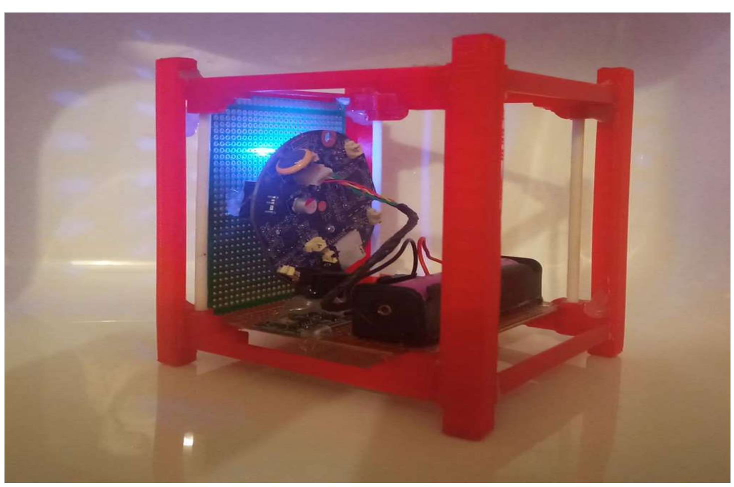


Figure 4.4: CubeSat 3D Printed Model

Inside a CubeSat structure, all the subsystems will be set up. Here, in the above Figure 4.2, only the camera and Electrical Power System (EPS) have been shown as payloads. Also, the above Figure 4.1, shows the 3D representation of Batteries, Electronic Power systems (EPS), Attitude Determination and Control systems (ADCS), Onboard Computer Systems (OBC), Communication systems (CS) and Solar panels.

4.3 CanSat 3D Model

According to the naming, CanSat is a soft drink can-shaped satellite mostly used for educational purposes and also used to simulate the bigger satellite. Whereas bigger satellites are costly and CanSat is very cost-efficient.

In the below Figure 4.3 a 3D representation of the CanSat. Its also show the inside view of a CanSat, whereas we see a battery and other subsystem.

CanSat payloads are very simple. Only single microcontroller, GPS sensors with other sensors like temperature and humidity, pressure, voltage regulators, Lithium batteries, cameras, communication antennas, is used to simulate this type of miniature satellite.

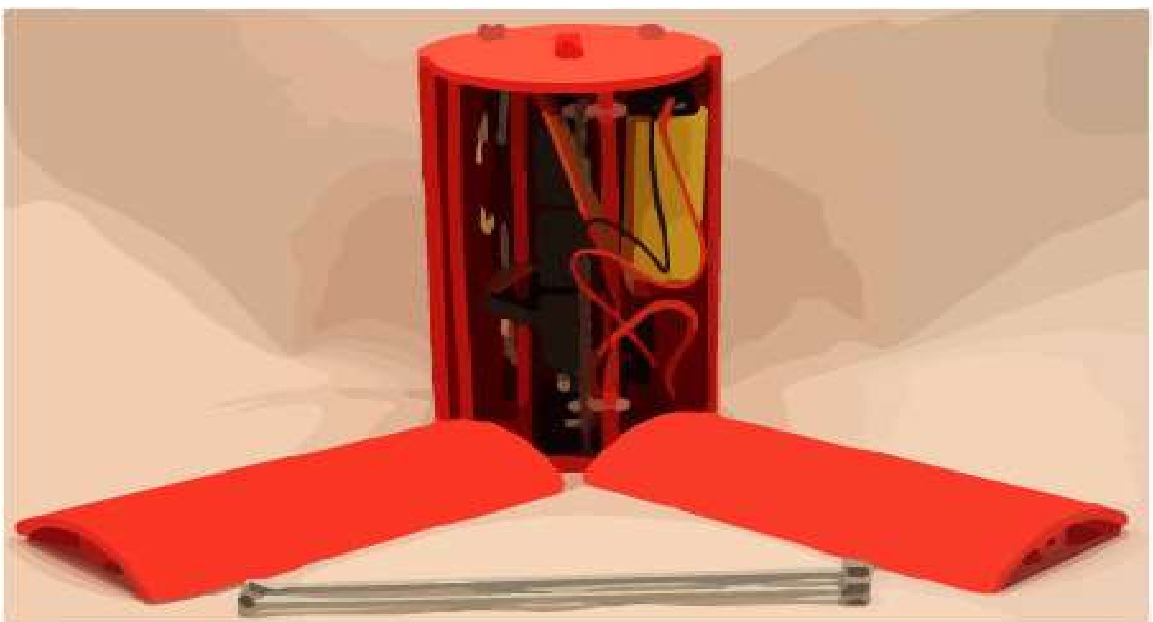


Figure 4.5: CanSat 3D Model

4.4 CubeSat Structure Comparison

Every CubeSat structure has its own physical body and each body has its own quality, because of its different construction material. The below table describes a comparison study with the previous CubeSat structure.

TABLE 4.1: CubeSat Structure Comparison Study

Year	Ref	Author Name	Materials	Stress (MPa)			Deformation	
				Yield Stress	X	Y	X	Y
2022	This study		ABS (filament)		2.774	42.14	1.866	1.250
2021	[24]	AYDINER et al	Al 6061-T6	276	17.076	64.154	0.0285	0.2871
	[25]	Gabriel et al	Thermal Analysis of a 3U-Cubesat.					
2020	[26]	Adham et al	Al 6061-T6	276	18.786	43.127	0.1501	0.021066
	[27]	Kapil Bharadwaj et al	Polyoxymethylene	0.384	0.384			
2019	[28]	Zhiyong Chen et al	PLA (filament)	40	8.06			
	[29]	Barsoum et al	Al 6061-T6	275	16.576		0.021	
	[30]	PAHONIE et al	Al 6061	276	20			
	[31]	Minh Chau et al	Al 6061	275	49.128	41.618	0.039	0.054
	[32]	Saul Piedra et al	Thermal Numerical Analysis					
2018	[33]	Adam et al	Al 7075-T6	503	207.08	226.2	0.067311	0.13225
					308.43			
2017	[34]	Emily et al	Al 6061-T6	193	5.927	11.937	9.3028	3.4371
					193			
2014	[35]	Nur et al.			9.6544	4.0837	3.5175	13.742

4.5 Conclusion

CubeSat structure is very important because all of the electronics are needed to be placed inside of its. Commonly its body built with Aluminum alloy 6061 or 7075 and designed with several mounting locations for components to allow flexibility in spacecraft configuration. Its structure also tested in Ansys simulation software, testing result is shown and discussed.

CHAPTER 5

CubeSat Subsystems

5.1 Introduction

A CubeSat consists of some electrical subsystems. Each subsystem has its own specific responsibilities to perform. The CubeSat designed to meet the specific requirements associated with the mission requirements. This chapter describes the CubeSat subsystems and their functionalities.

5.2 Electrical Power System (EPS) Engineering

Electrical Power Systems use solar cells as their primary source of energy. These solar cells are connected or mounted on the sides of CubeSat. The generated power is stored in two 18650 lithium polymer batteries. The Electrical Power System (EPS) is consisting of 3 major units named Power Management Unit (PMU), Solar Cells and Batteries. Also, this Electrical Power System distribute a stable power supply to the other subsystems.

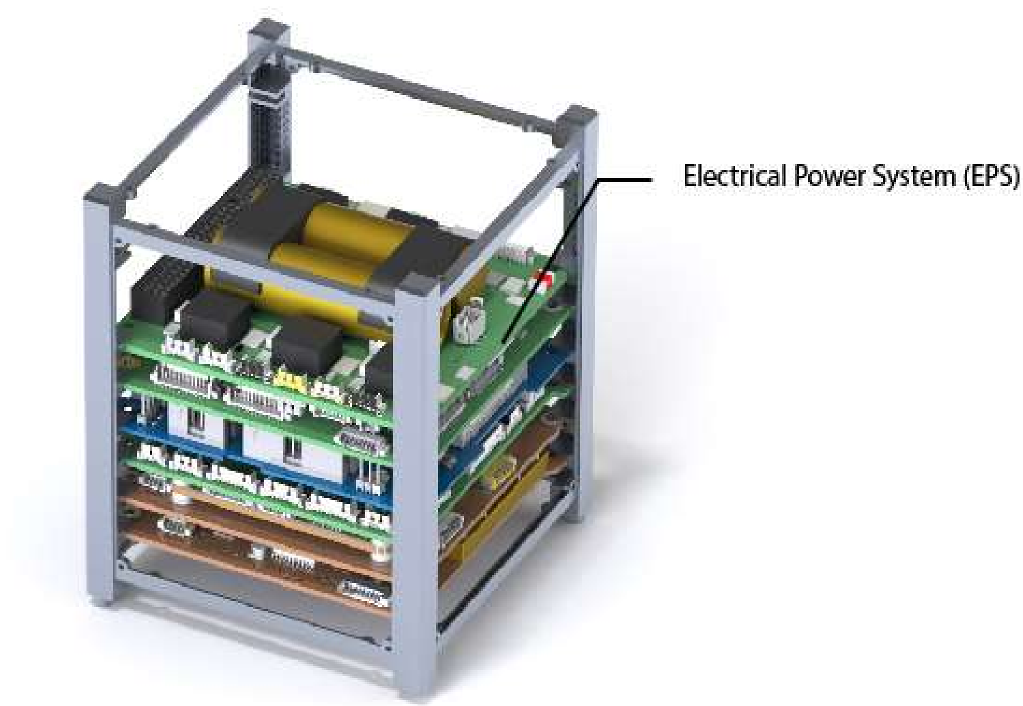


Figure 5.1: Electrical Power System (EPS)

5.2.1 Electrical Power System (EPS) Block Diagram

In the below Figure 5.1 shows how actually an Electrical Power System (EPS) works. Solar Panels are parallelly connected to the Battery Management Unit (BMU) and recharge the batteries when the Solar lights available on it. Battery management unit mainly electronic system that manages rechargeable batteries, such as by protecting the battery from overcharge and discharge. Power monitoring microcontroller monitors the batteries health issue and inform to the Onboard Computer OBC through I2C. Power Management Unit (PMU) is responsible to stable voltage distribution though its 5.5 and 3.3 voltage regulator.

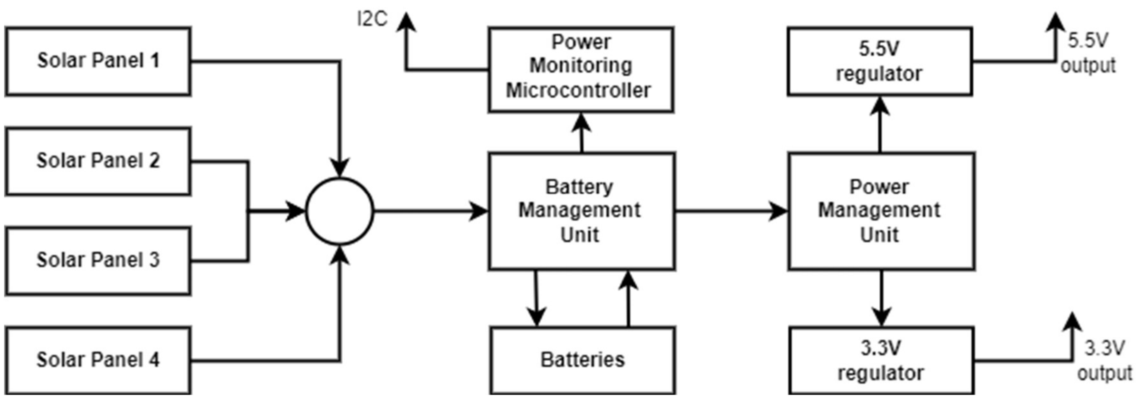


Figure 5.2: Electrical Power System (EPS) Block Diagram

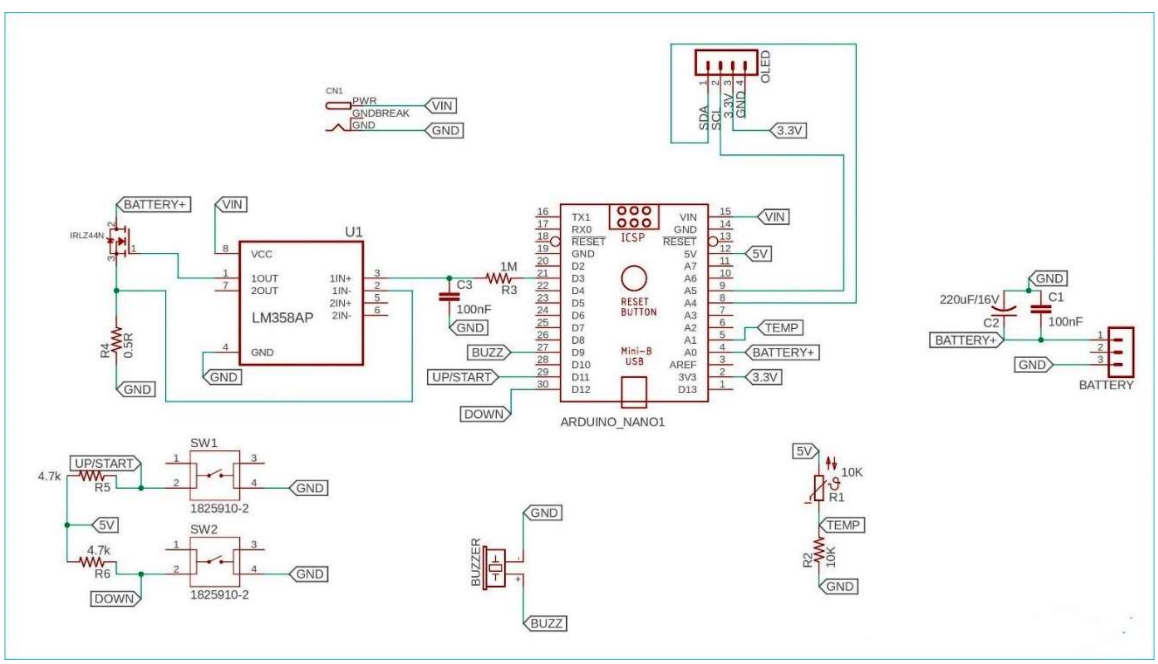


Figure 5.3: Power Monitoring Schematics (Capacity and Discharge)

5.2.2 Electrical Power System (EPS) Schematic Diagram

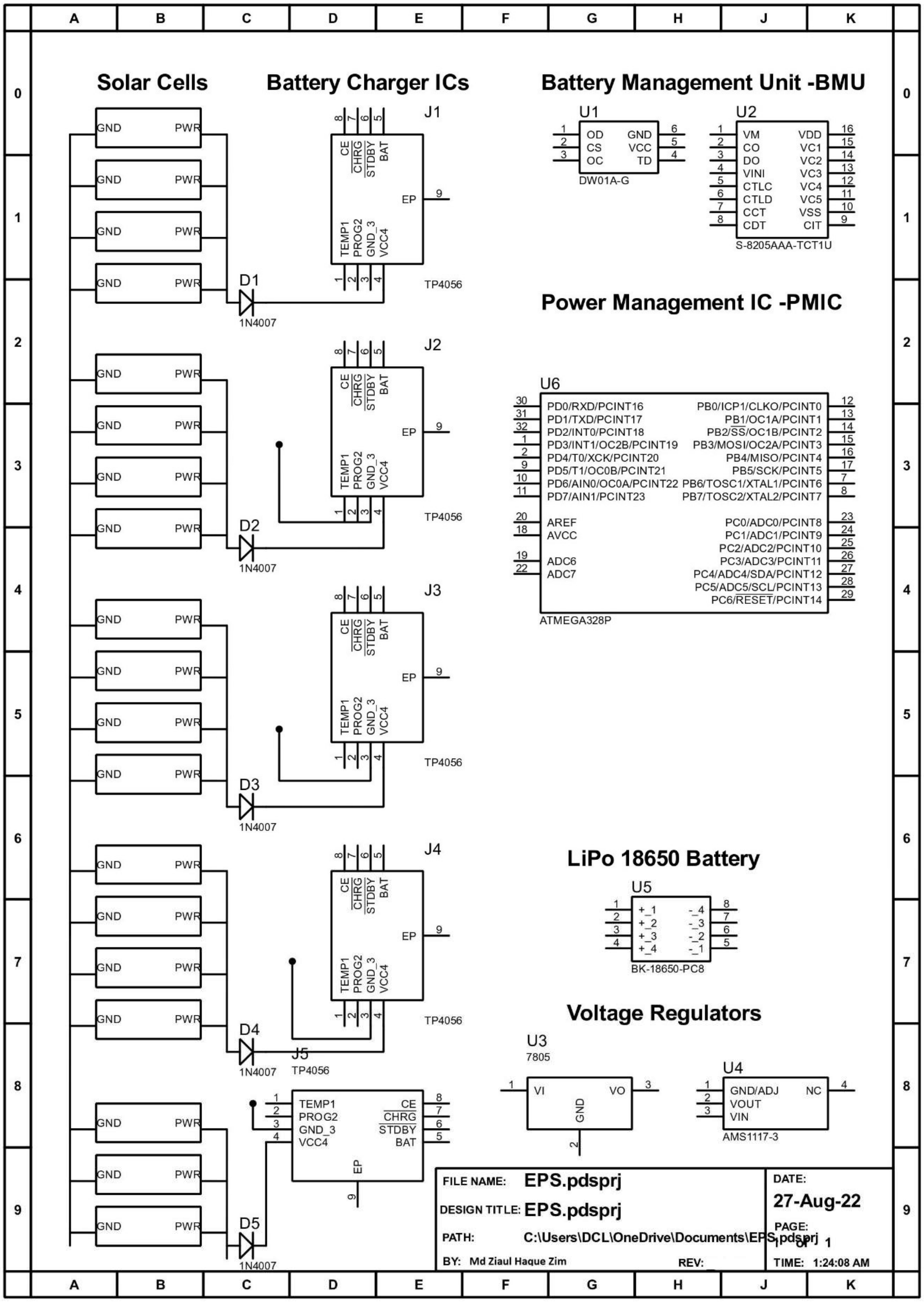


Figure 5.4: Electrical Power System (EPS) Schematic Diagram

5.2.3 Solar Power Management Unit

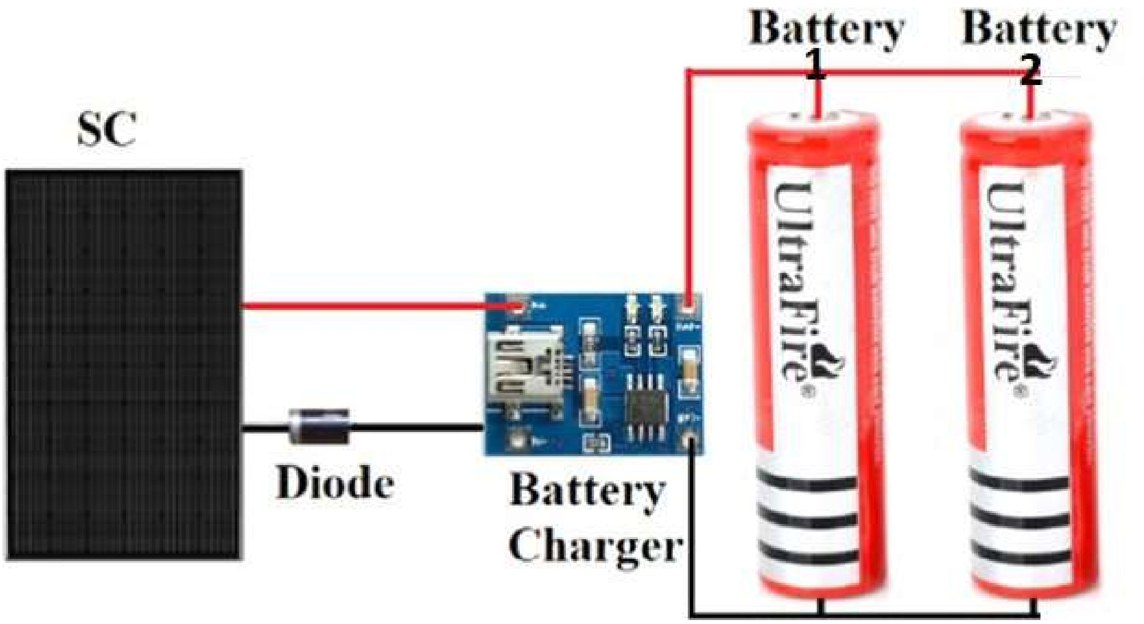


Figure 5.5: Solar Power Management Unit

Solar Power Management Unit basically gather energy from solar lights and then refers it to Battery Management Unit. A diode is used to prevent backflow of current.

5.2.4 Battery Management Unit – BMU

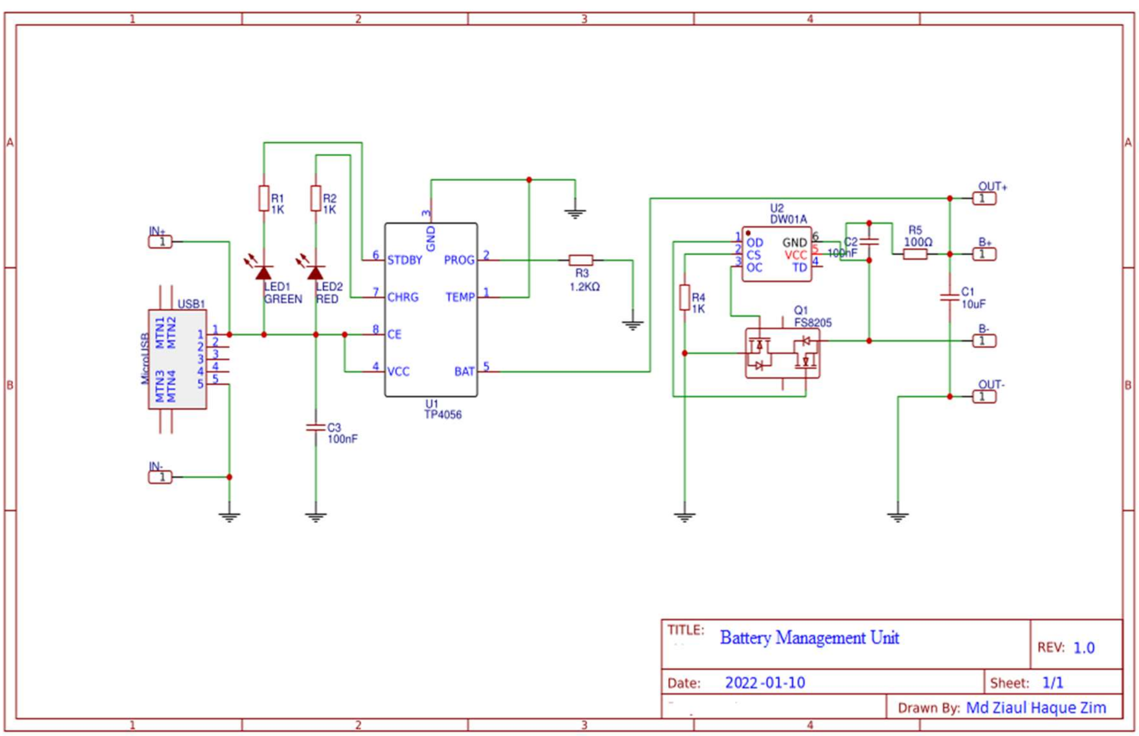


Figure 5.6: Battery Management Unit – BMU

In the Battery Management Unit (BMU) the TP4056 and the DW01A Li-Ion battery protection IC is used, which together in combination provide constant current to constant voltage charging, overcurrent and short-circuit, overcharge and over-discharge protection.

Figure 5.7: TP4056 Constant-Current/Constant-Voltage Linear Charger IC

Figure 5.8: DW01A Battery Protection IC

5.2.5 Power Management Unit – PMU

To distribute stable power to all subsystems a power management unit is playing the vital role. To supply 3.3v and 5v a voltage regulator is important. In Figure 5.3 there is 2 voltage regulator IC is used. 7805 is 5v and AMS1117 is 3.3v fixed linear voltage regulator.

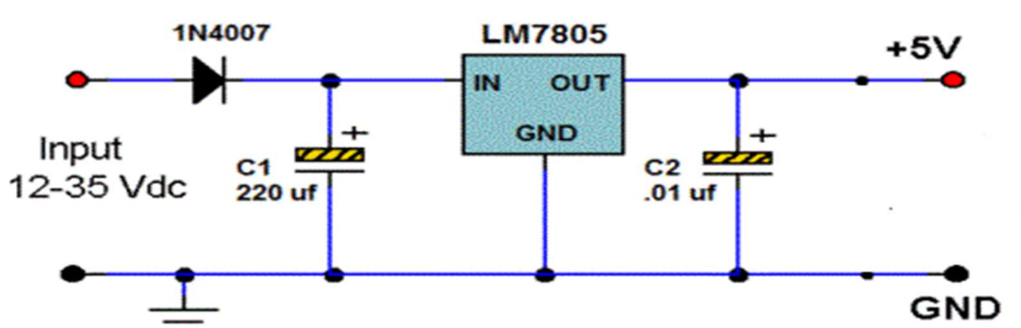


Figure 5.9: 5v Regulator Circuit in Power Management Unit – PMU

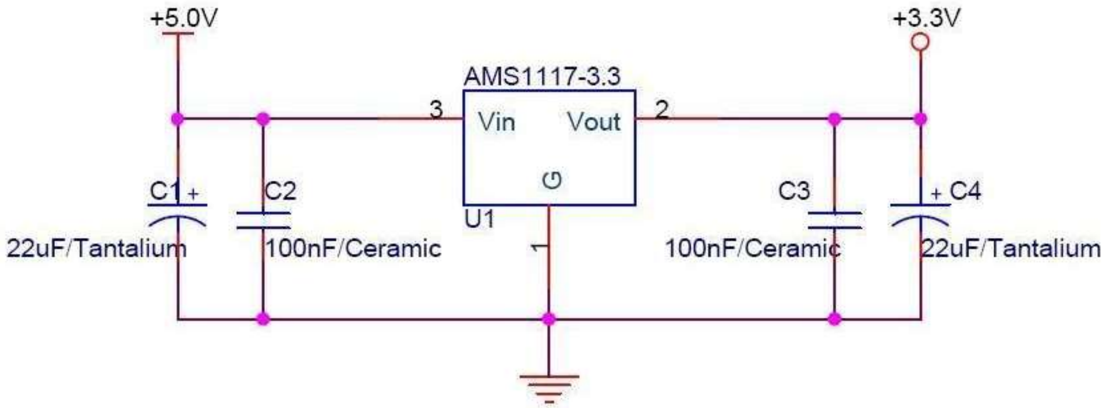


Figure 5.10: 3.3v Regulator Circuit in Power Management Unit – PMU

5.3 Attitude Determination and Control System – ADCS

To providing the pointing accuracy and stability an Attitude Determination and Control System – ADCS is very important. A CubeSat can determine its movement position and stability through this Attitude Determination and Control System (ADCS) by inertia measurement unit (IMU). An inertia measurement unit (IMU) measures and reports of the CubeSat physical body's specific forces and angular rate and sometimes the orientation of its own the body. Attitude Determination and Control System divided into two major parts. The first one who determine the inertia measurement unit of CubeSat own body and the second one who control the CubeSat orientation through actuators.

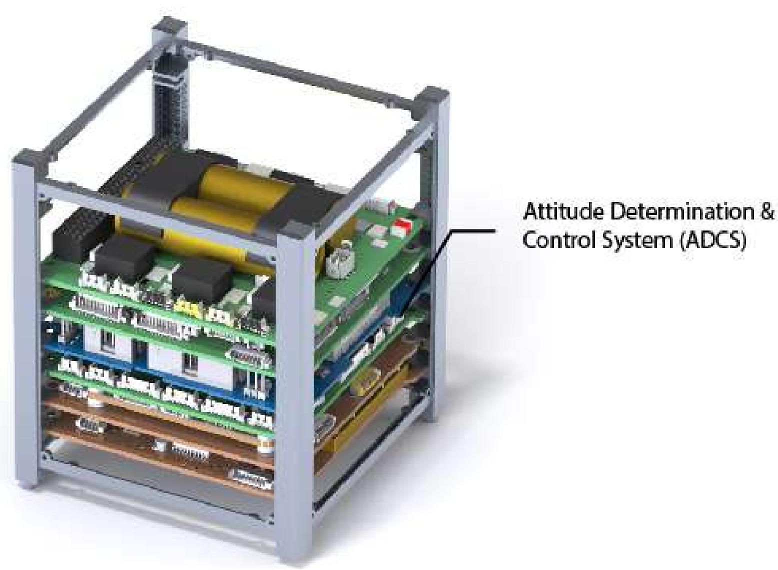


Figure 5.11: Attitude Determination and Control System – ADCS

5.3.1 ADCS Block Diagram

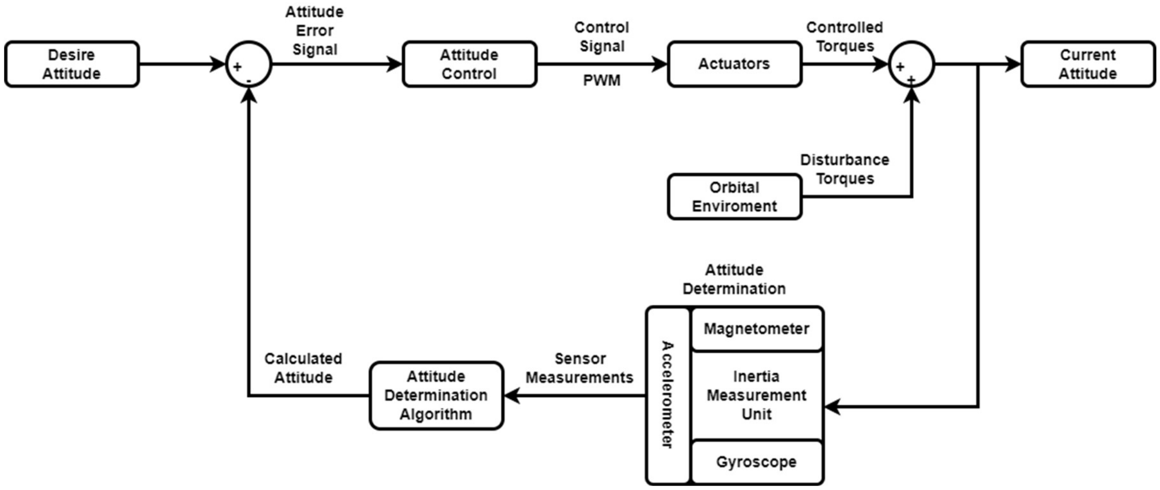


Figure 5.12: Attitude Determination and Control System – ADCS Block Diagram

In the above Figure 5.11, shows a crucial subsystem of a CubeSat. Attitude Determination and Control System – ADCS generally sense its stability through the inertia measurement unit (IMU). This inertia measurement unit (IMU) has a magnetometer, accelerometer and gyroscope to determine the accuracy and stability of the hole system.

5.3.2 ADCS Magnetometer HMC5883L

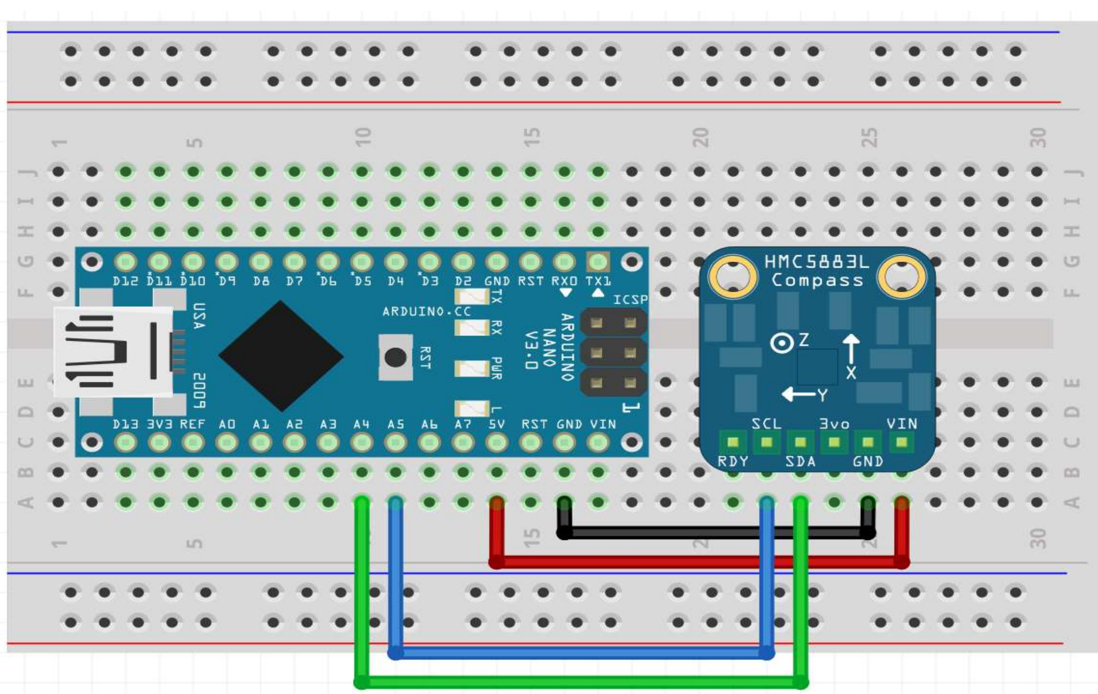


Figure 5.13: ADCS Magnetometer HMC5883L Interfacing with ATmega328P MCU

In the above Figure 5.12 shows the connection of HMC5883L with ATmega328P microcontroller (here, Arduino Nano is used which is equipped with ATmega328P microcontroller) via I2C and this HMC5883L determine the magnetic strength around it in 3 axes; X, Y and Z.

The below TABLE 5.1 showing the wiring connection between the HMC5883L and Arduino Nano.

TABLE 5.1: ADCS Magnetometer HMC5883L Wiring Connection with ATmega328P MCU

Wire	HMC5883L	Arduino Nano
Blue	SCL	A5
Green	SDA	A4
Red	VIN	5v
Black	GND	GND

5.3.3 ADCS Accelerometer ADXL 345 3-Axis

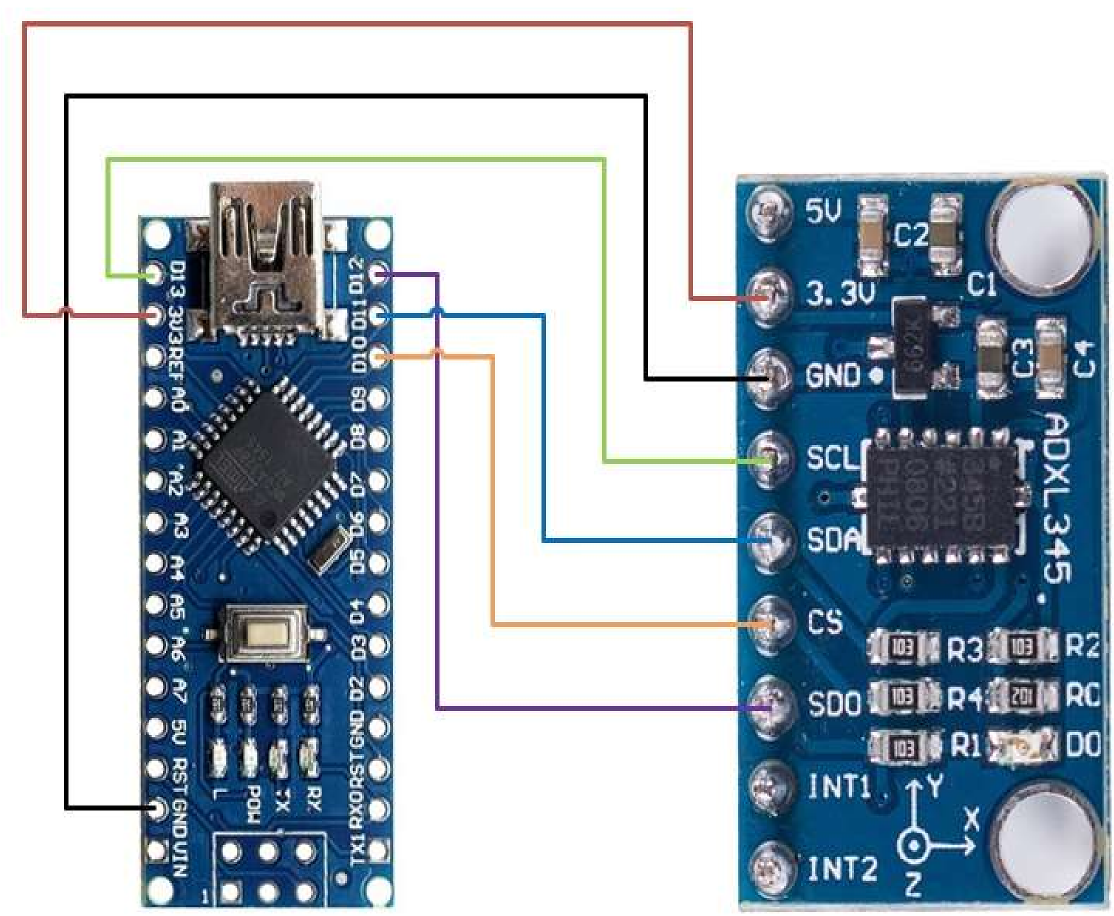


Figure 5.14: ADCS Accelerometer ADXL345 Interfacing with ATmega328P MCU

In the above Figure 5.13 shows the connection of ADXL345 with ATmega328P microcontroller (here, Arduino Nano is used which is equipped with ATmega328P microcontroller) via I2C and this ADXL345 a small, thin, low power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16g. This sensor is used to sense the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock.

The below TABLE 5.2 showing the wiring connection between the ADXL345 and Arduino Nano.

TABLE 5.2: ADCS Accelerometer ADXL345 Wiring Connection with ATmega328P MCU

Wire	ADXL345	Arduino Nano
Blue	SCL	D13
Green	SDA	D11
Violet	SDO	D12
Orange	CS	D10
Red	VIN	3.3v
Black	GND	GND

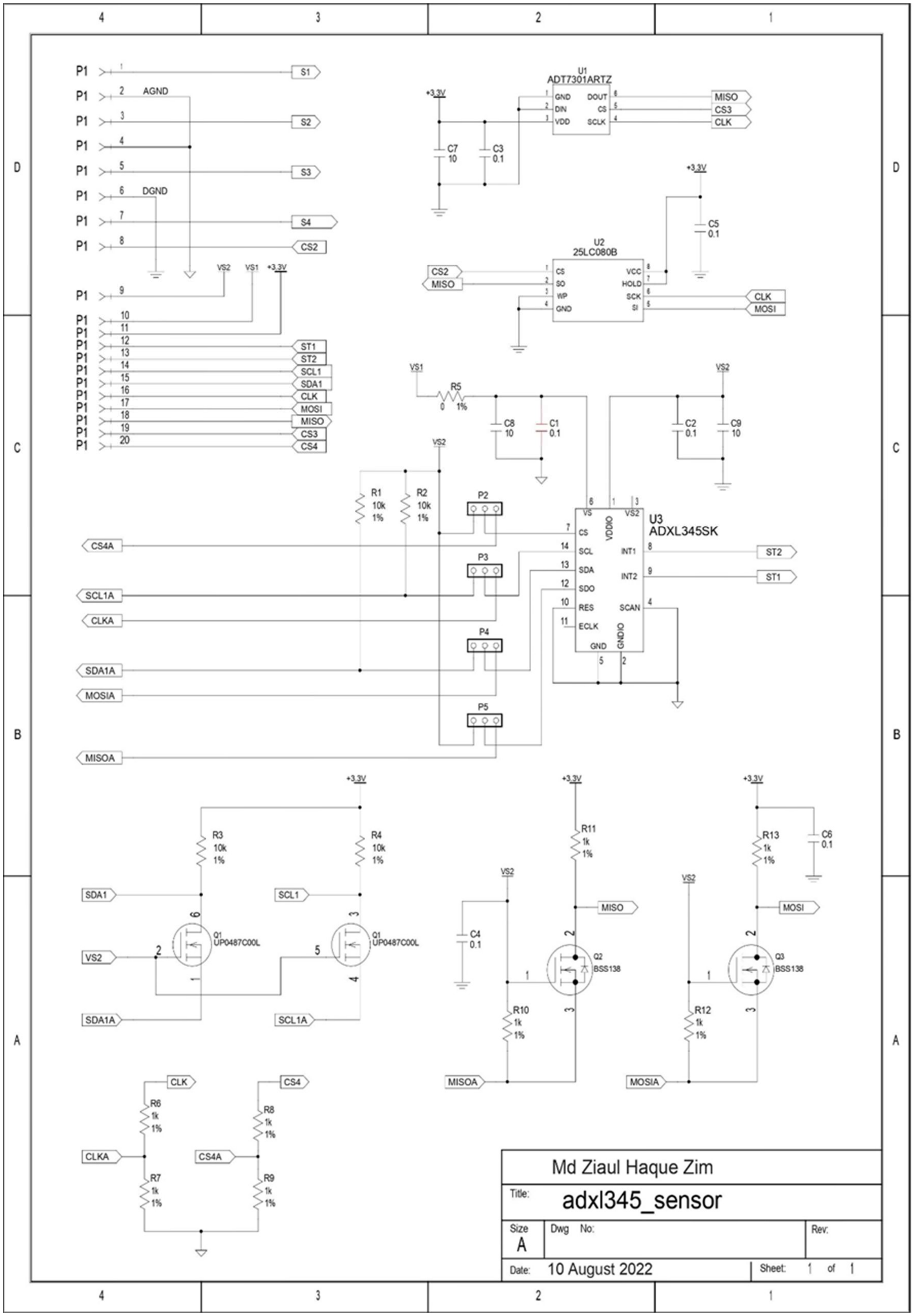


Figure 5.15: ADCS Accelerometer ADXL345 Schematic Diagram

5.3.4 ADCS Gyroscope MPU6050

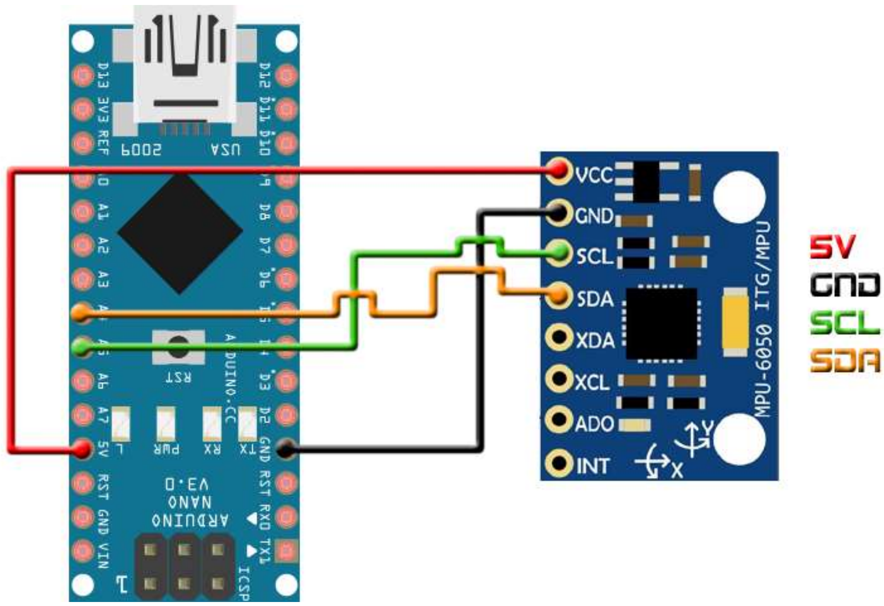


Figure 5.16: ADCS Gyroscope MPU6050 Interfacing with ATmega328P MCU

In the above Figure 5.14 shows the connection of MPU6050 with ATmega328P microcontroller via I2C and this MPU6050 a small, thin, low power, 3-axis accelerometer and , 3-axis gyroscope. The gyroscope sense by vibrations is picked by the capacitor when Coriolis effect causes a vibration and these happened when the gyros are rotated about any of its axes.

The below TABLE 5.3 showing the wiring connection between the MPU6050 and Arduino Nano.

TABLE 5.3: ADCS Gyroscope MPU6050 Wiring Connection with ATmega328P MCU

Wire	MPU6050	Arduino Nano
Blue	SCL	A5
Yellow	SDA	A4
Red	VIN	5v
Black	GND	GND

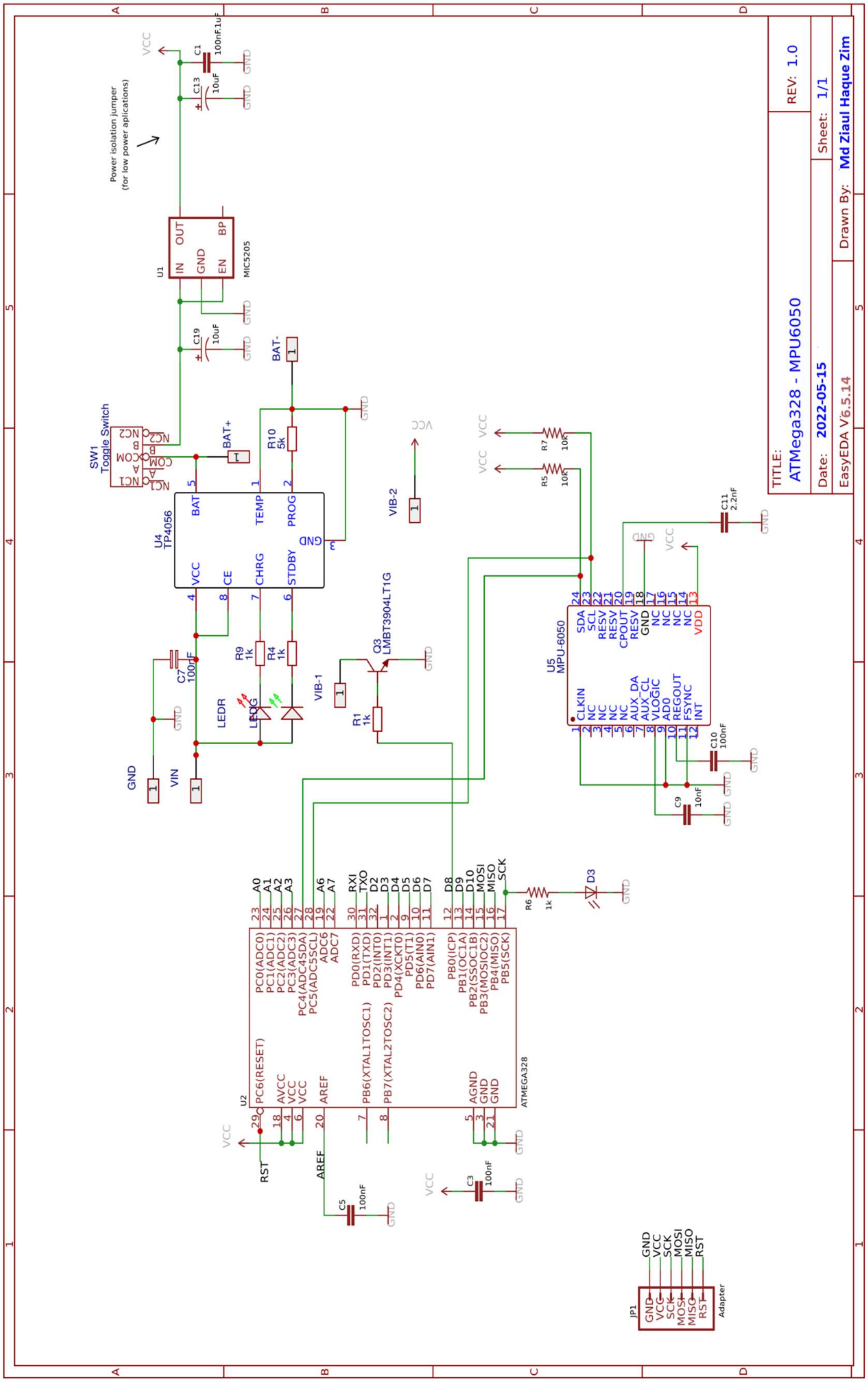


Figure 5.17: ADCS Gyroscope MPU6050 Schematic Diagram

5.3.7 Attitude Control Actuators

Control moment gyros, gravity-gradient stabilization, magnetic torquers, momentum wheels, solar sail, spin stabilization, thrusters and pure passive attitude control can be used as mechanisms for attitude control. Depending on the CubeSat size, weight and specifications several mechanisms obtained for the controlling the satellite attitude. But in this study, I used basic actuators for controlling the CubeSat.

5.4 On-board Computer System – OBC

Basically, onboard computer system (OBC) is a small computer mounted on CubeSat for its processing capability, command and data handling, communications that integrates the platform core, also works as a brain of the full system. Without this brain of CubeSat coordination of all the actions, sending orders to the different modules, the reception and storage of information cannot be possible. This onboard computer system (OBC) in any satellite and here in CubeSat works as a bridge to connects the other subsystems with each other.

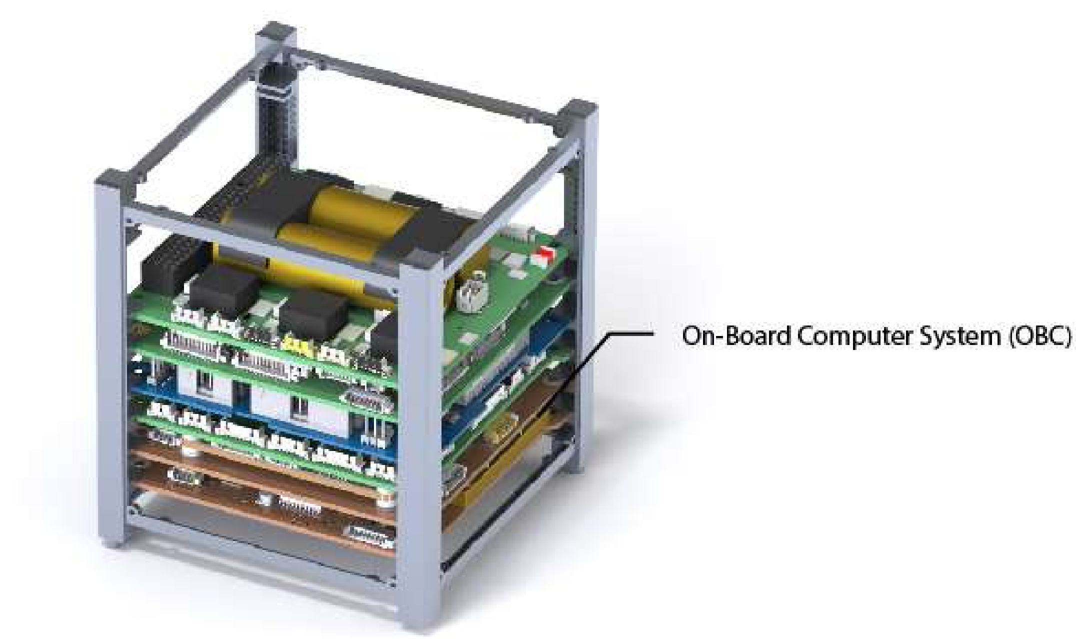


Figure 5.18: On-board Computer System – OBC

5.4.1 Architecture of OBC

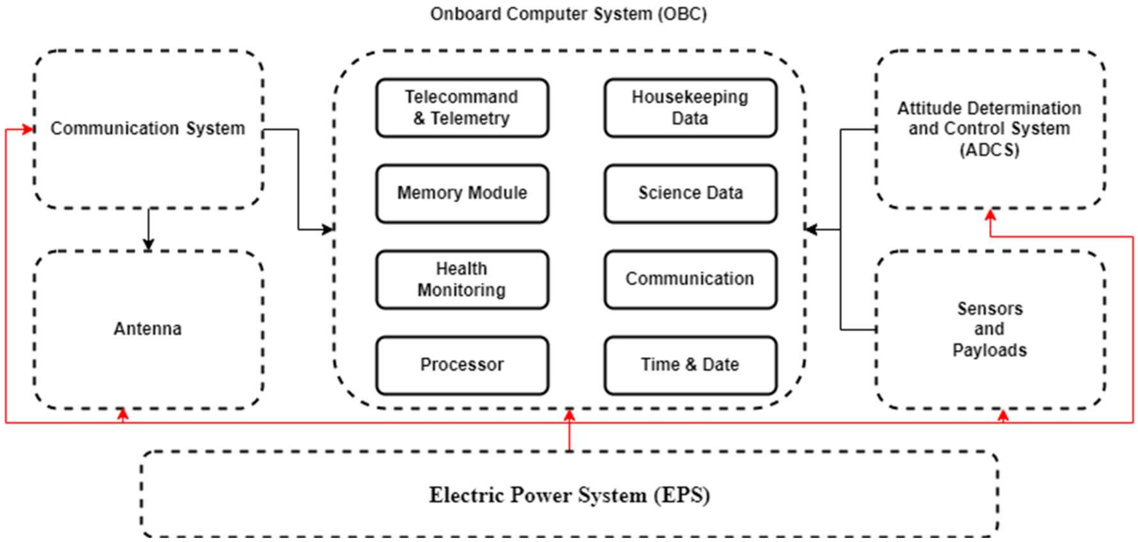


Figure 5.19: On-board Computer System – OBC Architecture

In the above Figure 5.18 shows the connectivity between subsystems within the CubeSat. In the CubeSat computing scheme, microcontroller's peripherals are configured according to the data flow through this On-board Computer System – OBC. In this study, A Raspberry Pi Zero is used as an On-board Computer System (OBC). In the below Figure 5.19 describe about its on-circuit equipment's.

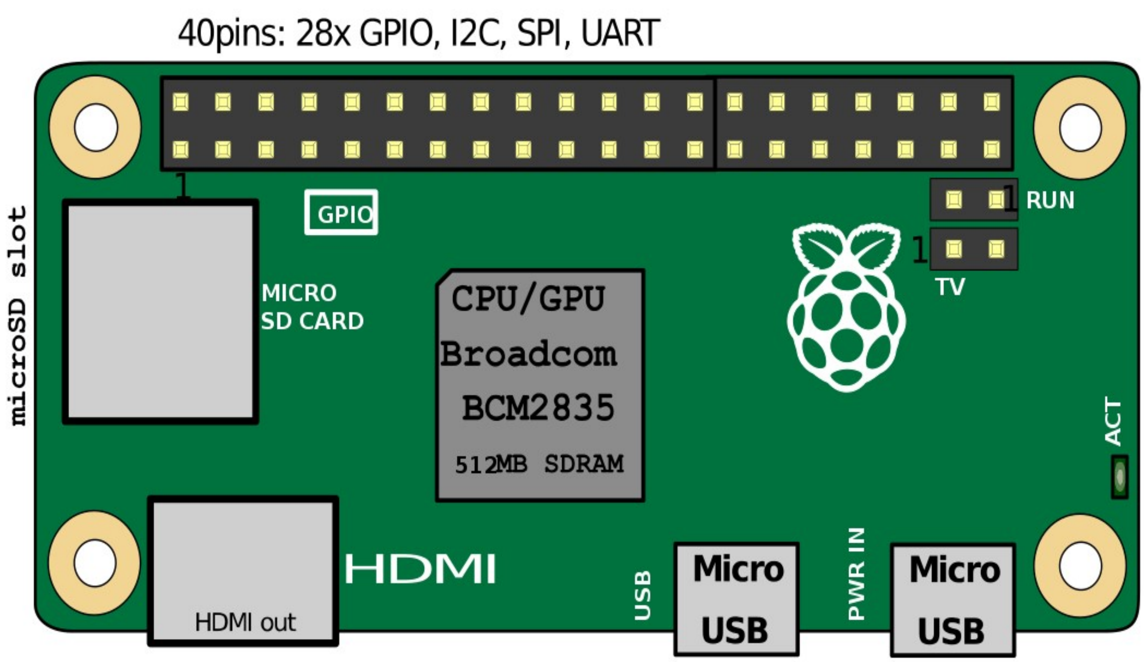


Figure 5.20: On-board Computer System – OBC

5.4.2 Block Diagram of OBC

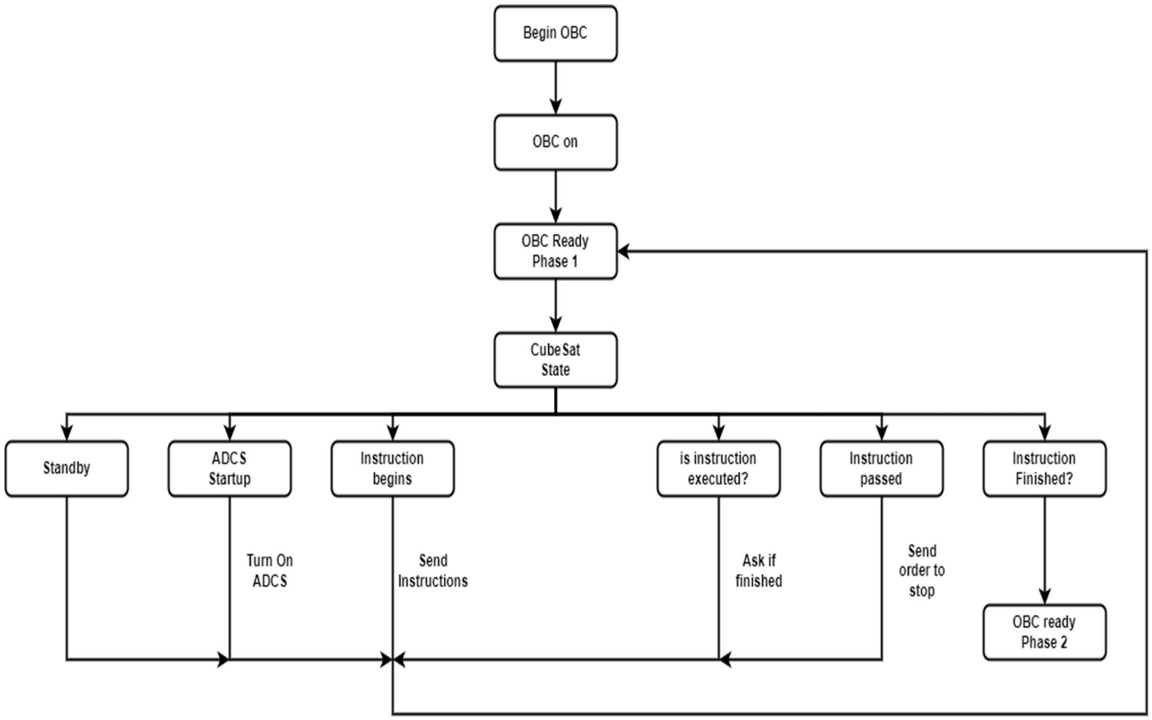


Figure 5.21: On-board Computer System – OBC Flowchart Diagram

In the above Figure 5.19 shows an On-board computer system (OBC) flowchart diagram. After the initialization, the OBC turns on the Attitude Determination and Control System (ADCS), then send order to the ADCS to determine of its attitude after that it stabilize the CubeSat. On-board Computer System sends regular command to ask if the instruction phase is finished. When it is finished, an order is sent to stop the running instruction and the next loop will begins.

5.4.3 Processor

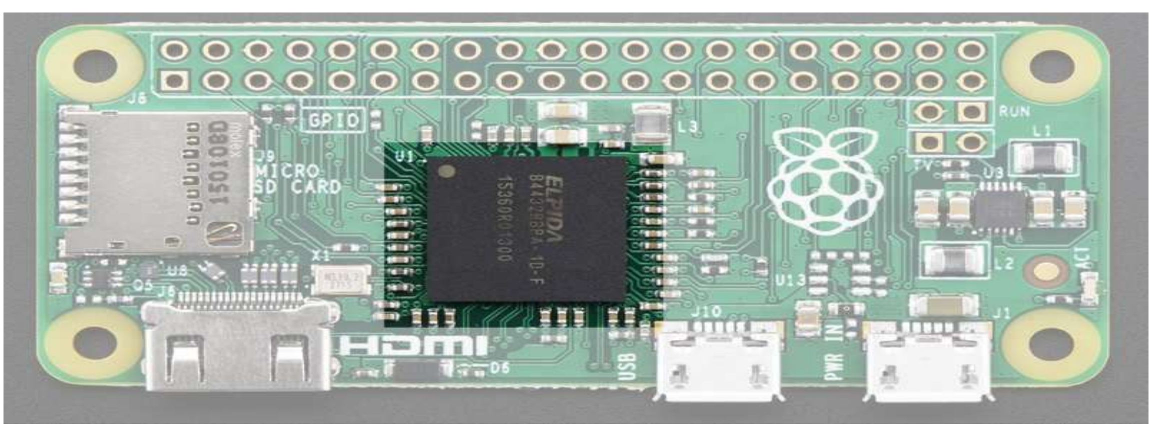


Figure 5.22: On-board Computer System – OBC Processor

A single-core 1GHz ARM processor will have an impact on the power consumption and the efficiency for the calculation. In the above Figure 5.19 shows the processor of Raspberry Pi Zero, which is used as a processor in this study.

5.4.4 Random Access Memory – RAM

The Random-Access Memory or RAM is commonly used to store the data as the processor needs it. In this study, the processor has an inbuilt 512 MB RAM itself. Which is satisfying our system demand.

5.4.5 Read Only Memory – ROM

The ROM or Read Only Memory used will be both flash memory and EEPROM. If the onboard computer system - OBC has to shut down due to energy/malfunction issues the EEPROM will hold the program. Flash memory is used to store the programs and data.

5.4.6 Operating System

To work with the embedded system there are a big number of OS that exists. But for CubeSat o miniature satellite, there is only two OS mainly used. Which are FreeRTOS and Salvo. In this study, I used FreeRTOS to microcontroller-based systems.

5.5 Communication Systems – CS

The CubeSat communication system using radio waves to transmit signals to the antennas on the Earth. Then the antennas on Earth ground station receive those signals and process the information coming from those signals. The CubeSat communication system received the signals from ground station then process it through the onboard computer system (OBC) and execute the instruction that is received from the ground station.

In this study, I used LoRa Ra-02 as transmitter & receiver for the communication. The term LoRa stands for Long Range and it extends the range of my CubeSat communication. LoRa is a spread spectrum modulation technique. There are different types of LoRa modules available in the market. I used SX1278 LoRa Module which is commonly called as SX1278 Ra-02 which operates on 433MHz.

From Ground Station, I used same module for receiving the transmitted signal from CubeSat. This SX1278 Ra-02 have the sensitivity of over -148dBm using a low-cost crystal.

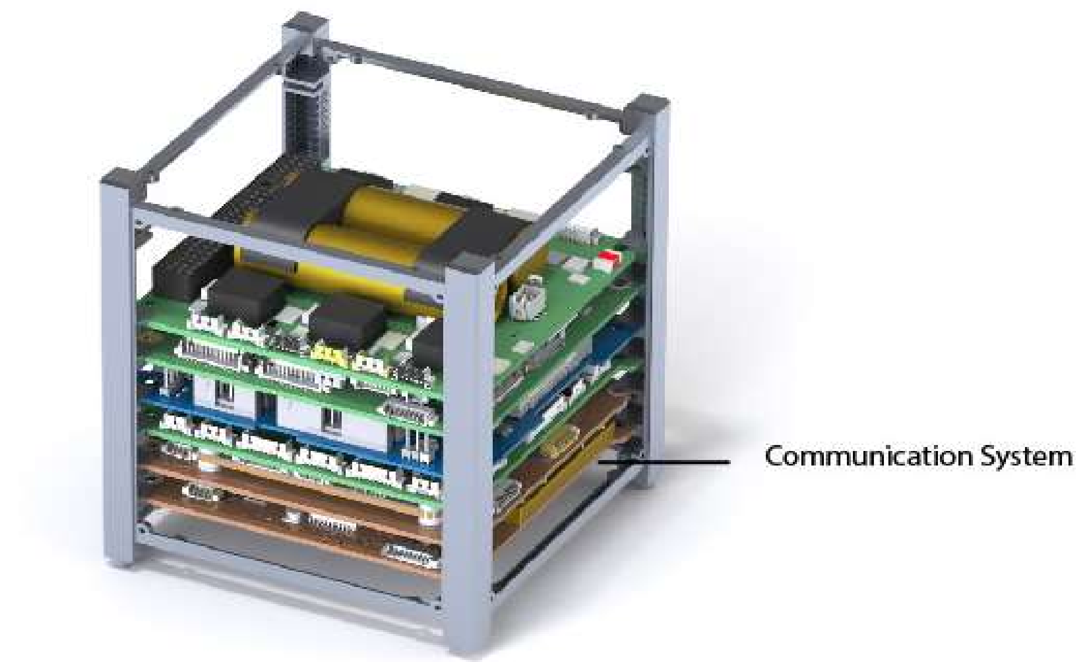


Figure 5.23: Communication Systems – CS

5.5.1 Communication Systems Architecture

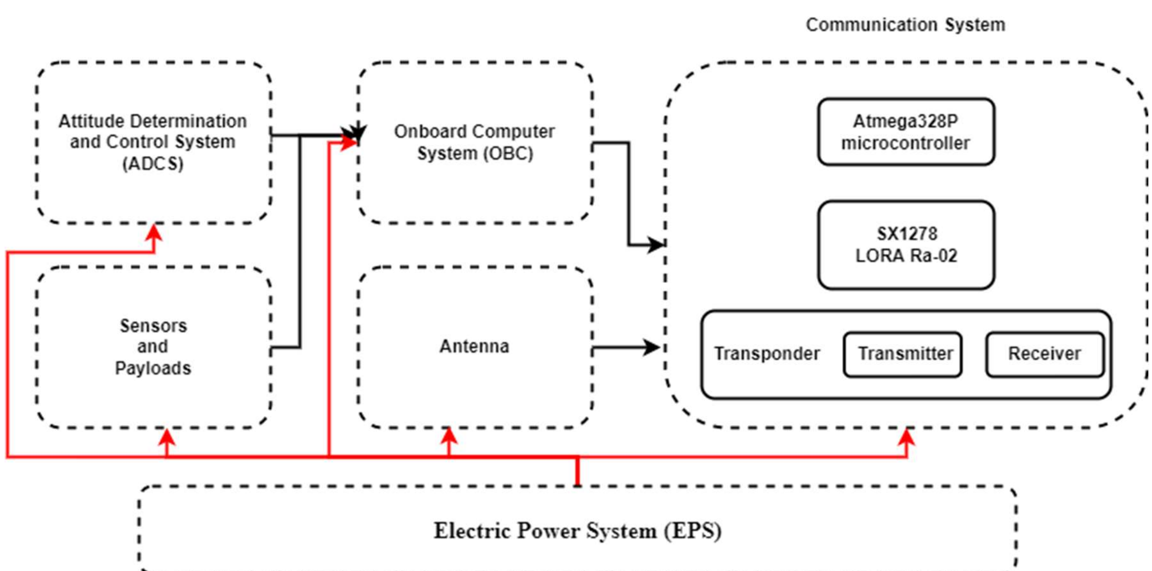


Figure 5.24: Communication Systems - CS Architecture

The communication system consists of an SX1278 Lora Ra-02, an atmega328p microcontroller and an antenna.

5.5.2 SX1278 LoRa Ra-02 Interfacing

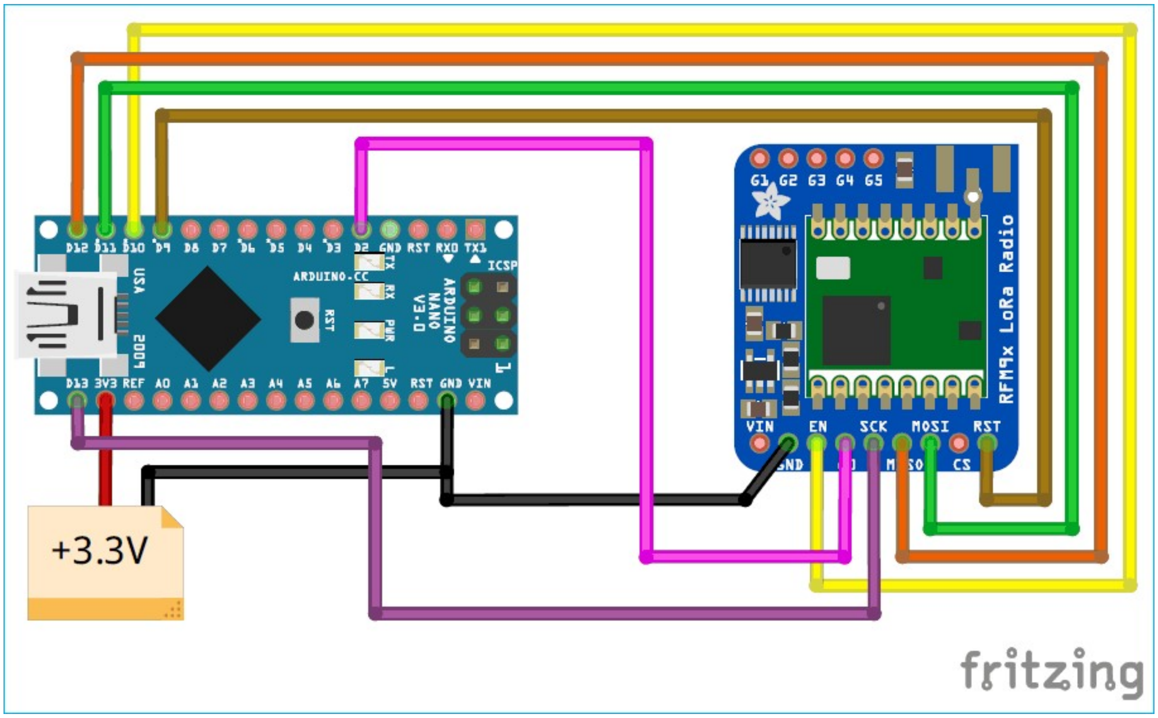


Figure 5.25: SX1278 LoRa Ra-02 Interfacing with ATmega328P (Arduino Nano)

In the above Figure 5.21 showing SX1278 LoRa Ra-02 interfacing with ATmega328P (Arduino Nano) and below TABLE 5.4 showing the wiring connection. LoRa is a spread spectrum modulation technique. There are different types of LoRa modules available in the market. I used SX1278 LoRa Module which is commonly called as SX1278 Ra-02 which operates on 433MHz. The Arduino Nano boards have I2C and UART communications. I2C is used to communicate with OBC to sending and receiving data from the Ground Station.

TABLE 5.4: SX1278 LoRa Ra-02 Wiring Connection with ATmega328P (Arduino Nano) MCU

LoRa SX1278 Module	Arduino Nano Board
3.3V	3.3V
GND	GND
En/Nss	D10
G0/DIO0	D2
SCK	D13
MISO	D12
MOSI	D11
RST	D9

5.6 Antenna

In CubeSat, antenna is very crucial part. To communicate with each other in space and ground station to carry out many functions such as remote sensing, research, wide area measurements and deep space communication an antenna is very important part. And for designing antenna for CubeSat is very critical because of weight restrictions, matching size and good antenna radiation performance. There are many types of antennas for CubeSat. Planar antennas, helical antennas, radiation patterns, gain, dipole antennas, reflect array antennas, reflection coefficient.

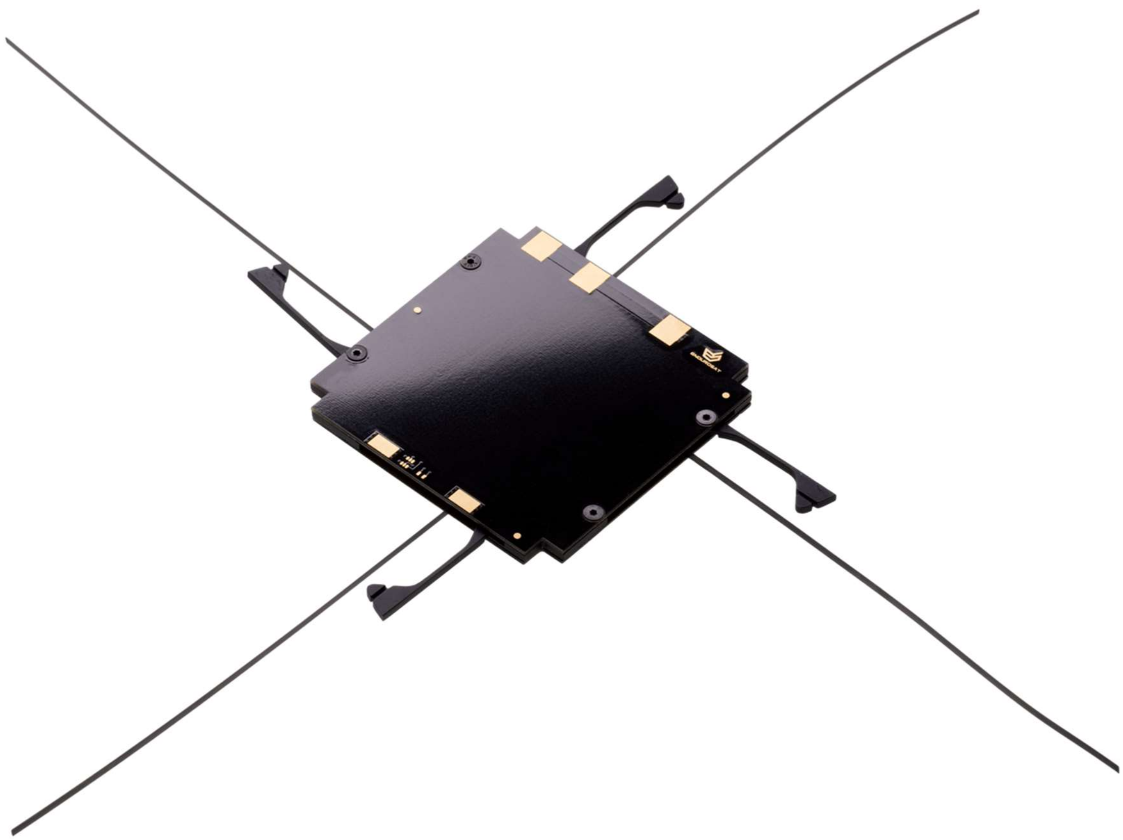


Figure 5.26: CubeSat Antenna

In this study, I am using SX1278 LoRa Ra-02 module to complete the communication part. For that 433Mhz spring antenna is used to complete this communication part.

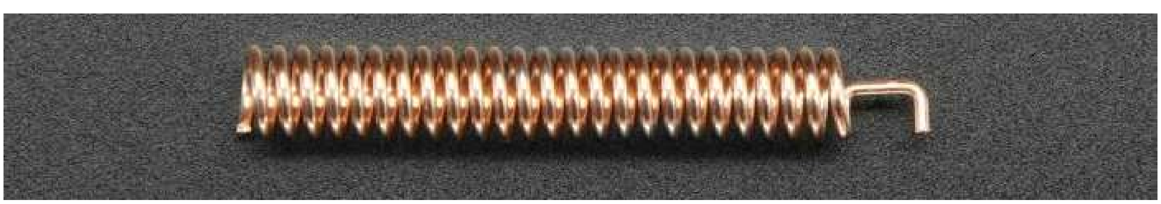


Figure 5.27: CubeSat Spring Antenna

5.6.1 : Comparative Analysis of Antenna with Previous Studies

TABLE 5.5 : Comparative Analysis of Antenna with Previous Studies

Band	Type	Sat Type (Unit)	Operating Frequency	Center Frequency	Bandwidth (%)	Gain (dBi)	Size (mm)	Deployable	PCB	Ref
VHF	Dipole	3	146 MHz	-18.5 dB	13.7	2.06	0.26	Yes	Yes	[36]
		1	144 MHz	-14.5 dB	8.68	2.6	1.42	Yes	No	[37]
	Monopole	1	144 MHz	-35 dB	4.86	2.14	0.45	Yes	No	[38]
	Helical	3	270 MHz	-19 dB	6.15	3.56	0.35x0.35	Yes	No	[36]
		3	350 MHz	-19 dB	6	4.7	0.35x0.35	Yes	No	[37]
UHF	Slot	1.5	(485/500) MHz	-29 dB	n/a	4	n/a	No	No	[40]
	Dipole	3	438 MHz	-21 dB	6.85	3.35	0.26	Yes	Yes	[41]
		1	435 MHz	-15 dB	5	3.91	1.42	Yes	No	[38]
	Monopole	1	435 MHz	-42 dB	5.98	4.35	0.45	Yes	No	[42]
	Helical	3	550 MHz	-20 dB	78.7	8.44	0.22x0.22	Yes	No	[43]
		1.5	400 MHz	n/a	n/a	13	1.83x0.47	Yes	Yes	[44]
		3	450 MHz	-19 dB	4.67	5.41	0.35x0.35	Yes	No	[45]
		6	365 MHz	-27 dB	7.12	8.38	0.1x0.12	Yes	Yes	[47]
	Yagi-Uda	1.5	435 MHz	-19 dB	12.18	11.5	n/a	Yes	Yes	[48]
	Meanderline	n/a	437 MHz	-22 dB	5	4.1	2.52x1.24	Yes	No	[49]
L	Patch	3	1.57 GHz	-27 dB	9.55	6	0.80x0.80	No	Yes	[50]
S	Patch	3	2.45 GHz	-45 dB	44.90	8.22	0.78x0.78	No	Yes	[51]
		3	2.43 GHz	-14.5 dB	1.65	5.3	0.23x0.35	No	Yes	[52]
		1	2.45 GHz	-19 dB	2.45	4.8	0.19x0.20	No	Yes	[53]
		3	2.45 GHz	-32.5 dB	45.75	8.5	0.27x0.72	No	No	[54]
		6	3.6 GHz	n/a	n/a	30.5	1.2x1.2	Yes	Yes	[55]
			2.2 GHz	-40 dB	9.66	5.4	0.80x0.80	No	Yes	[56]
		1	2.43 GHz	-16 dB	2.67	7.2	0.81x0.81	No	Yes	[57]
		3	2.45 GHz	-22 dB	33.01	4	0.70x0.70	No	Yes	[58]
		3	2.25 GHz	-18.5 dB	11.11	4.87	0.75x0.75	No	No	[59]
	Slot	3	2.45 GHz	-21 dB	30.20	9.71	0.73x0.73	No	Yes	[58]
		2	2.45 GHz	-30 dB	4.45	8.62	0.29x0.29	No	No	[59]
		1	2.44 GHz	-34 dB	2.05	5.8	0.31x0.31	No	Yes	[60]
	Dipole	1	2.45 GHz	-27.35 dB	4.8	5.03	0.66x0.66	No	No	[61]
		1	2.45 GHz	-27.5 dB	33.46	3.49	0.45x0.45	No	No	[62]
	Patch	3	2.52 GHz	-23.5 dB	11.11	5.2	0.67x1.51	No	Yes	[63]
	Inflatable	3	2.45 GHz	n/a	n/a	25	0.72x0.72	Yes	No	[64]
	Patch	1	2.30 GHz	-40 dB	28.70	4.39	0.46x0.20	Yes	No	[65]
	Yagi-Uda	3	2.47 GHz	-26.47 dB	5.42	6.41	n/a	No	No	[66]
C	Patch	1	5.1 GHz	-17 dB	10.20	5.9	1.41x1.17	No	No	[67]
		1	5.8 GHz	-21 dB	1.2	6.98	1.93x1.93	No	No	[68]
		3	8 GHz	-19 dB	2.39	6.45	2.13x2.13	No	Yes	[69]
	Slot	1	5 GHz	-17 dB	1.99	4.98	1.18x0.39	No	Yes	[70]
	Helical	6	8 GHz	n/a	62.5	12	3.2x0.8	No	No	[71]
X	Patch	1	8.25 GHz	-40 dB	16.97	13	n/a	No	No	[72]
		1	7.4 GHz	-13 dB	16.21	7.2	n/a	No	Yes	[73]
		3	11.2 GHz	-15.5 dB	3.22	5.34	2.13x2.13	No	Yes	[74]
		1	10 GHz	-18 dB	40	15	3.33x3.33	No	Yes	[75]
	Reflector	6	8.425 GHz	n/a	n/a	28	9.34x5.58	Yes	Yes	[76]
	Reflect array	6	8.425 GHz	n/a	n/a	29.2	5.58x9.40	Yes	Yes	[77]
	Horn	6	10 GHz	-23 dB	11.11	17.5	2x4	Yes	No	[78]
	Patch	1	8.2 GHz	-15 dB	15.85	20.03	2.73x2.73	No	No	[79]
	Reflector	12	8.45 GHz	n/a	n/a	36.8		Yes	Yes	[80]
Ku	Reflect array	6	8.4 GHz	n/a	n/a	39.6	42.8x42.8	Yes	Yes	[81]
	Helical	1	12.2 GHz	-22.5 dB	15.57	8.5	0.73x0.73	No	Yes	[82]

K/Ka	Reflector	6	34 GHz	n/a	n/a	42.8	56.70	Yes	Yes	[83]
	Reflect array	3	26 GHz	n/a	n/a	33	29.38x7.15	Yes	Yes	[84]
	Reflector	12	7.1675 GHz	n/a	n/a	36.1		Yes	Yes	[85]
			8.435 GHz			36.8				[86]
			32 GHz			48.7				[87]
			34.45 GHz			48.4				[88]
	Metasurface	1	32 GHz	-17 dB	6.35	24.4	5 (radius)	No	Yes	[89]
W	Reflector	6	86 GHz	-24 dB	9.88	34.36	28.73x28.73	No	Yes	[90]
	Metasurface	1	94 GHz	<-15 dB	2.12	3.9	56x56	No	Yes	[91]
mm and Sub-mm	Horn	3	140, 249, 309	n/a	n/a	20	n/a	No	No	[92]
	Reflector	6	165, 176, 180, 183	n/a	n/a	16-18	n/a	No	Yes	[93]
	Reflector	3	883	n/a	n/a	n/a	n/a	No	Yes	[94]

5.6.2 GPS Antenna

GPS stands for Global Positioning System. That is receive satellite signal and give exact location. Depending on the satellite requirement and feature there are many types of antennas which is used to for getting the GPS signals. In this study I am using NEO-6M GPS module which used U.FL ceramic antenna.

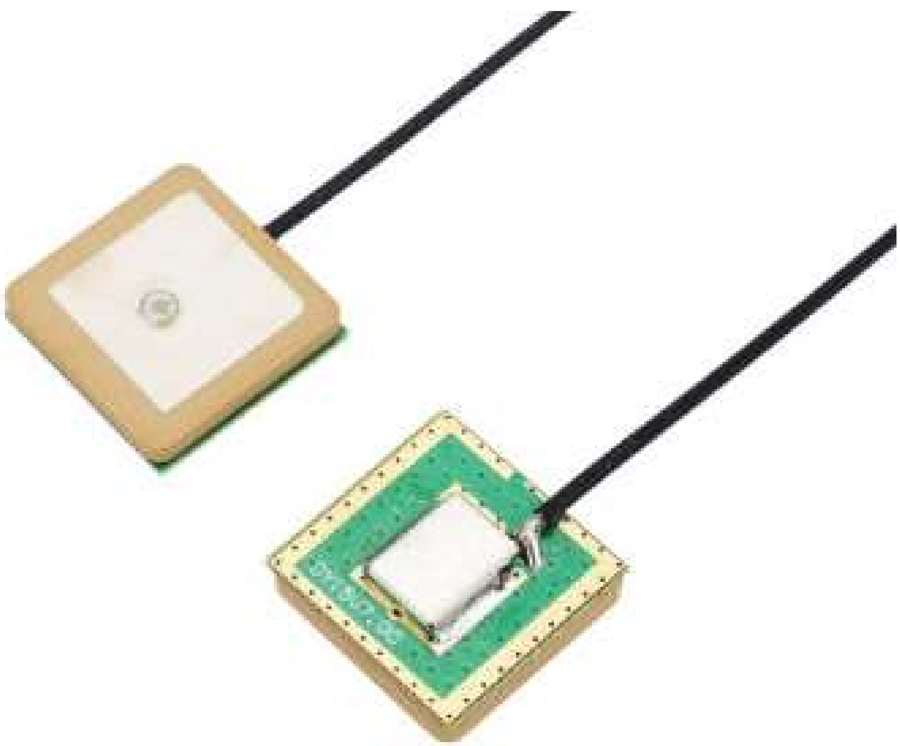


Figure 5.28: U.FL Ceramic Antenna

5.7 Conclusion

With the combination of Electrical Power System (EPS), Attitude Determination and Control System (ADCS), On-board Computer System (OBC) and Communication System (CS) a CubeSat will build. They are vitally important part of a CubeSat and with the help of each other subsystem a CubeSat will run his mission in the orbit. So that as an engineer or developer, we need to secure highest science to develop each of these.

CHAPTER 6
CanSat Subsystems

6.1 Introduction

A CanSat consists of some electrical subsystems. Each subsystem has its own specific responsibilities to perform. But it's not had a powerful onboard computer system (OBC). The CanSat designed to meet the specific requirements associated with the mission requirements. This chapter describes the CanSat subsystems and their functionalities. CanSat is mainly used for educational or training purposes. By the name of the can, it looks like a soft drink can and the main challenge of its developer fit all the major subsystems found in a satellite, such as power, sensors and a communication system, into this minimal volume. The CanSat never left the atmosphere, nor orbited the earth.

Figure 6.1: CanSat

6.2 CanSat Structure

CanSat is mainly used for educational or training purposes. By the name of the can, it looks like a soft drink can and the main challenge of its developer fit all the major subsystems found in a satellite, such as power, sensors and a communication system, into this minimal volume. A CanSat 3D model is designed via Adobe Fusion 360.

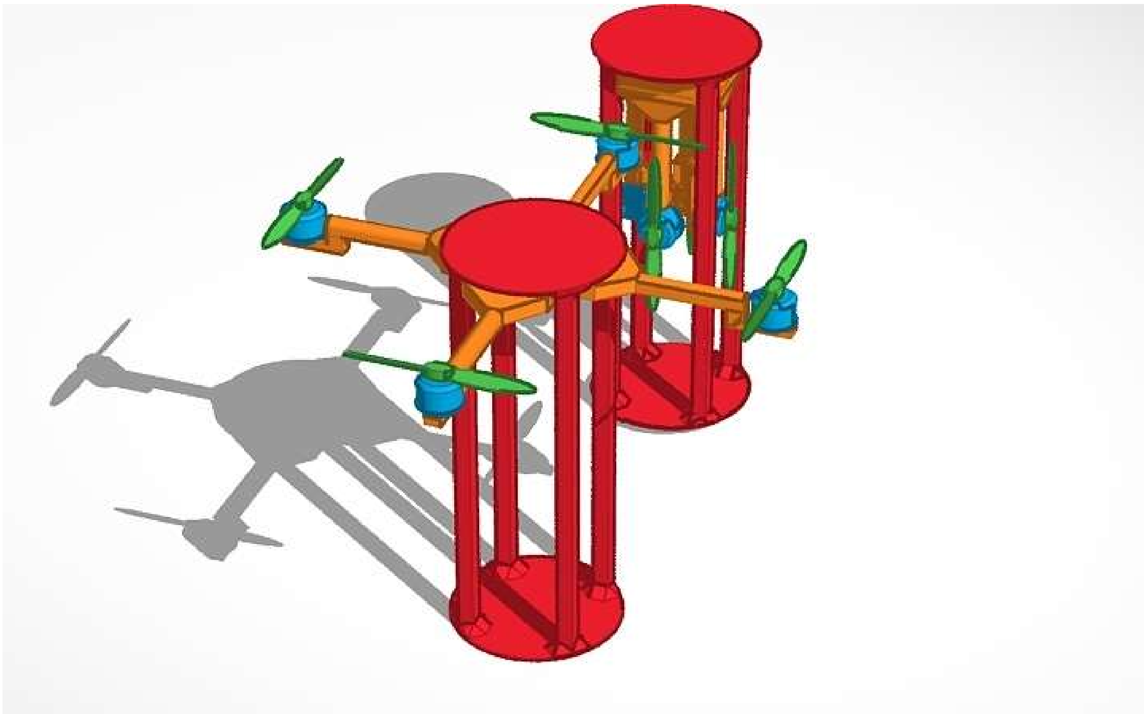


Figure 6.2: CanSat 3D Model

6.3 Electrical Power System – EPS

CanSat Electrical Power System is very basic subsystem that will power up the full system and distribute a stable power supply for the mission. Basically, it contains lithium polymer batteries, low voltage alarm circuit and voltage regulator ICs.

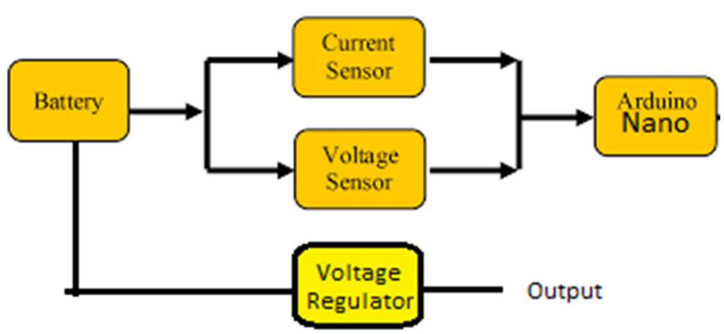


Figure 6.3: CanSat Electrical Power System – EPS

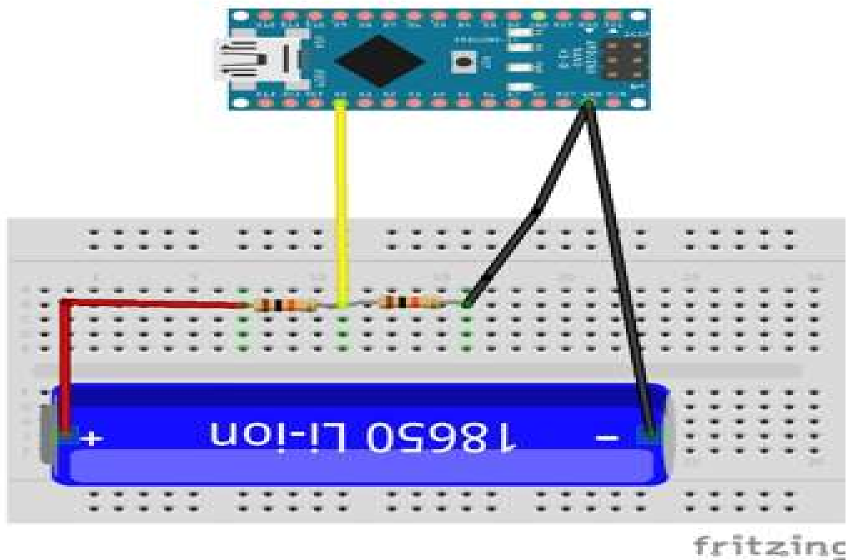


Figure 6.4: CanSat Voltage Divider for voltage measurement

6.4 Onboard Computer - OBC

For the CanSat Onboard Computer – OBC I used a ATmega328P microcontroller-based development board. In the below Figure 6.5 CanSat onboard computer as Arduino Nano pin out diagram is shown,

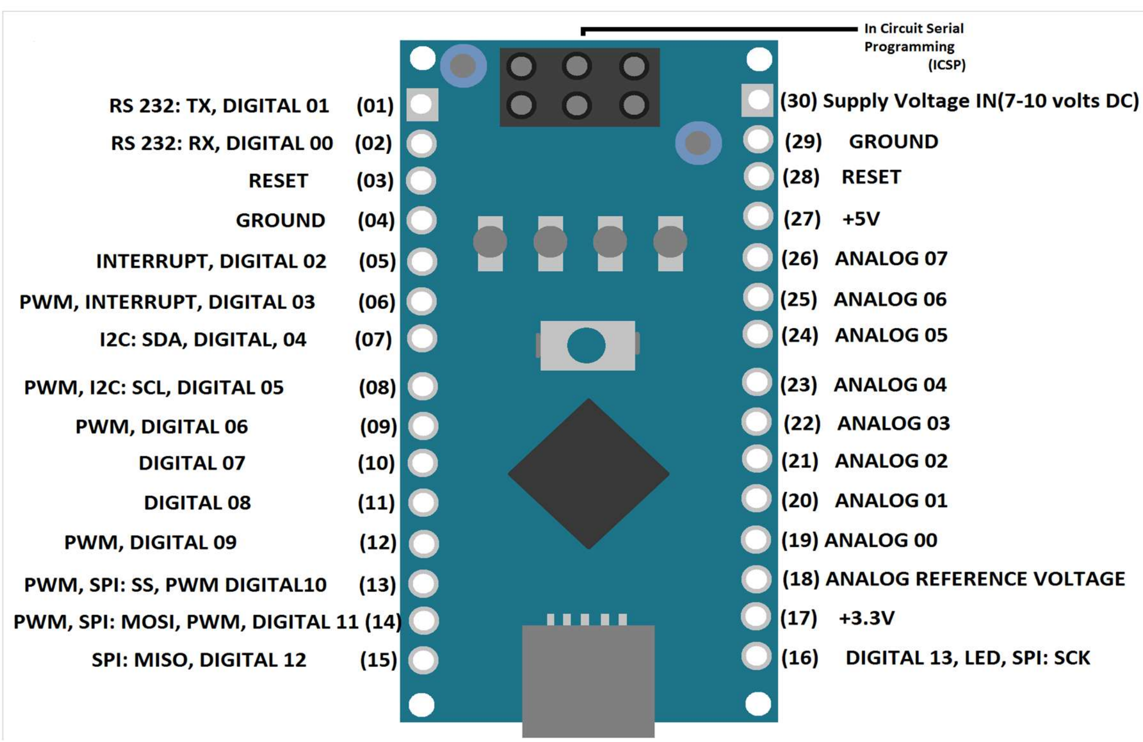


Figure 6.5: CanSat Onboard Computer Pin Out Diagram

The CanSat system also integrated with a 5MP Camera. For image data handling, processing and telemetry a ESP32 Cam is integrated with the subsystem. An interfacing is shown between Arduino Nano and ESP32 Cam module in the below Figure 6.6.

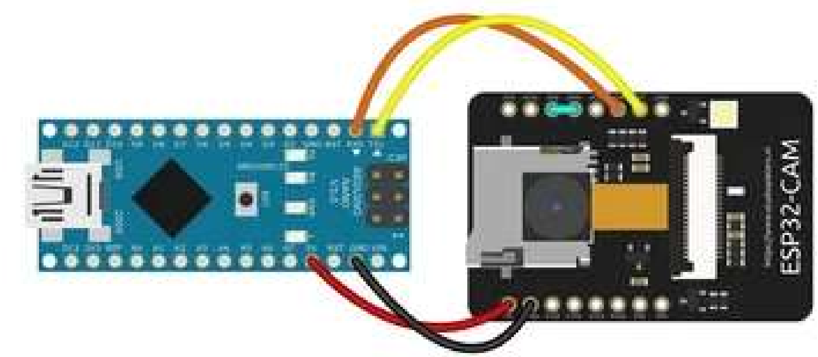


Figure 6.6: CanSat Camera

The CanSat velocity, stability and the acceleration a MPU6050 3-Axis accelerometer and 3-Axis gyroscope module is used. An interfacing is shown between Arduino Nano and MPU6050 module in the below Figure 6.7.

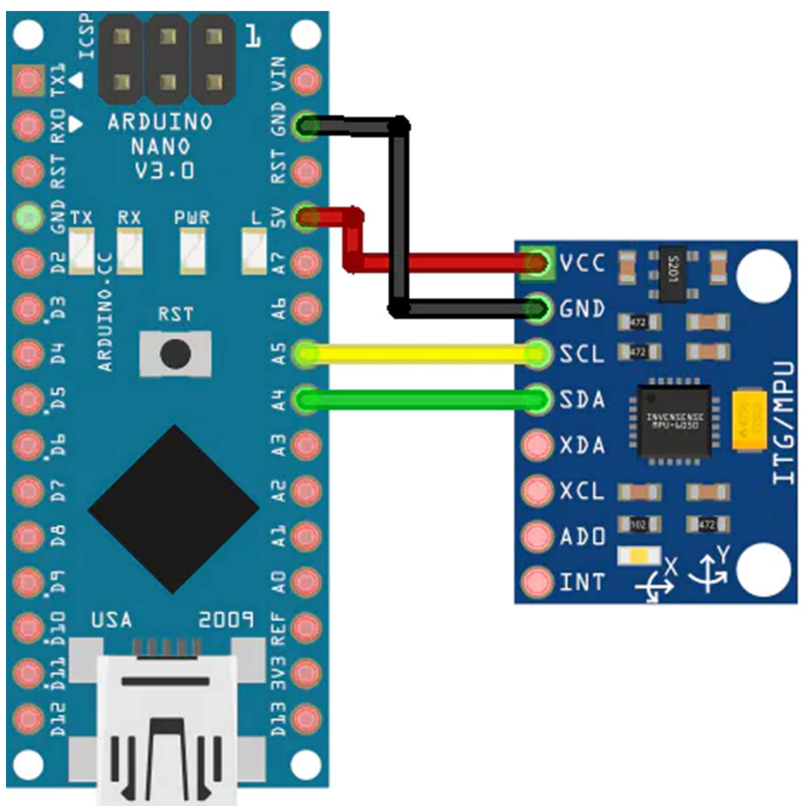


Figure 6.7: CanSat Inertia Measurement Unit (IMU), MPU 6050 interfacing with Arduino Nano

For measuring the atmospheric pressure, I used BMP280 pressure sensor to the system. An interfacing is shown between Arduino Nano and BMP280 module in the below Figure 6.8.

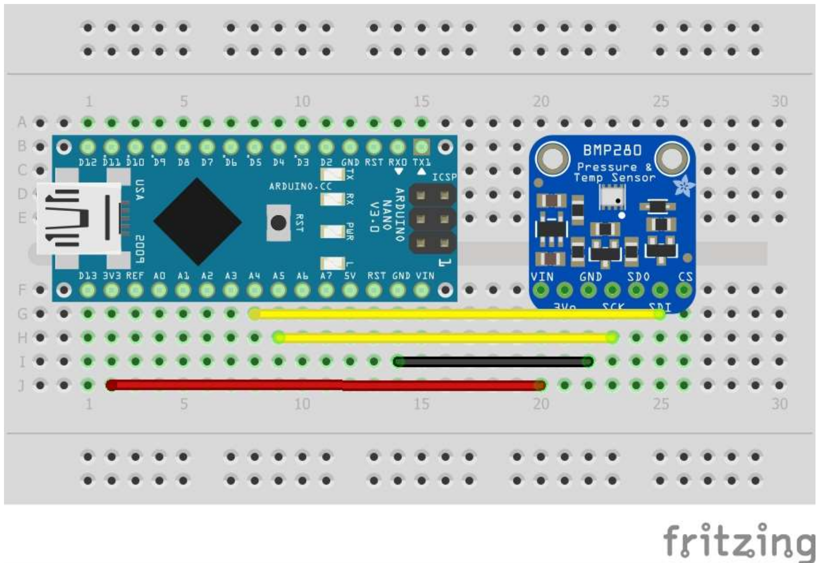


Figure 6.8: CanSat Pressure Measuring Sensor BMP280 interfacing with Arduino Nano

For measuring the vibration, I used SW-420 vibration sensor to the system. An interfacing is shown between Arduino Nano and SW420 vibration module in the below Figure 6.9.

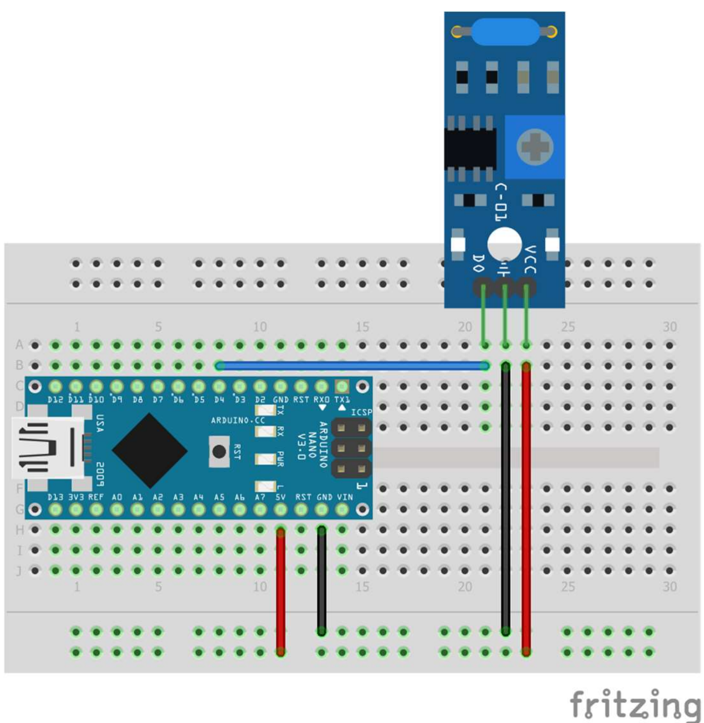


Figure 6.9: CanSat Vibration Sensor SW-420 interfacing with Arduino Nano

6.5 Global Positioning System – GPS

For getting the location of a CanSat, a GPS subsystem is mandatory. I used NEO 6M GPS Module to the system. An interfacing is shown between Arduino Nano and NEO 6M GPS module in the below Figure 6.10.

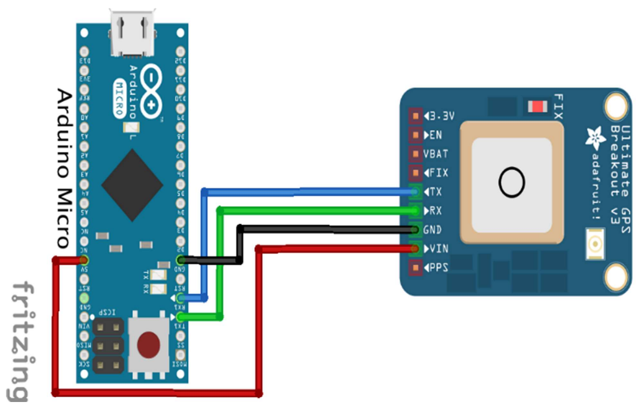


Figure 6.10: CanSat Global Positioning System – GPS

6.6 Communication Subsystem

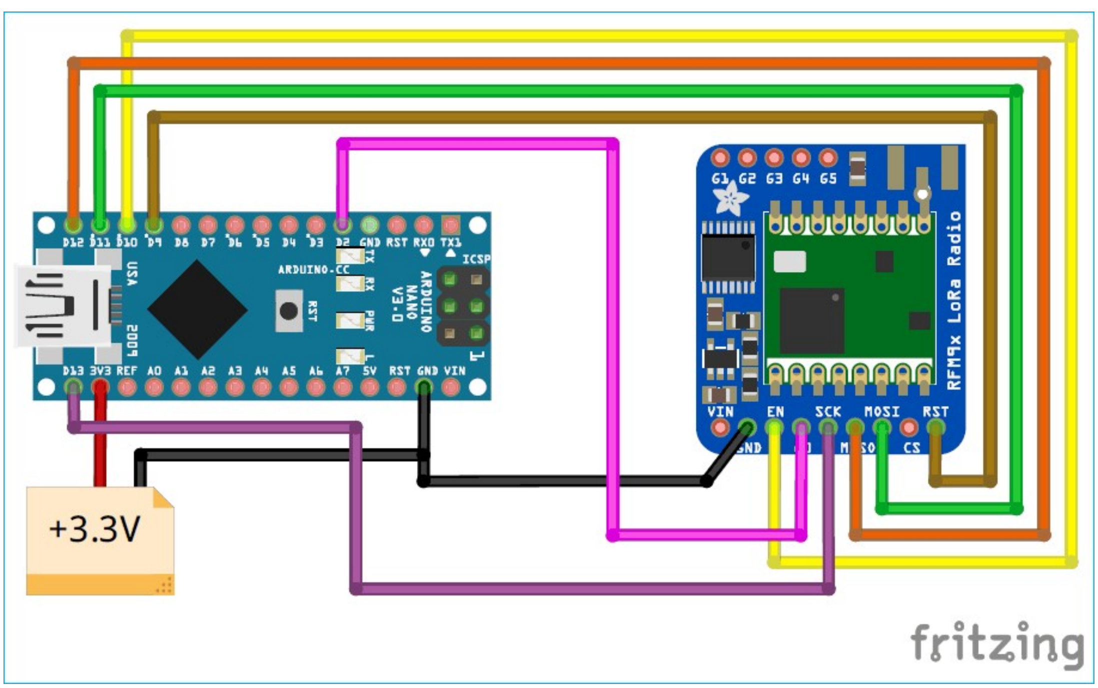


Figure 6.11: CanSat Communication Subsystem

The Communication System is running on this CanSat is based on LoRa module, which is consists of 16 pins with 8 pins on each side. Out of these 16 pins, 6 are used by GPIO pins ranging from DIO0 to DIO5 and four are used by Ground pins. The module operates in 3.3V and hence the 3.3V pin on LoRa is connected to the 3.3v pin on the Arduino Nano development board. Then I connect the SPI pin on the LoRa to the SPI pins on Arduino Board as shown above Figure 6.11.

7.7 Conclusion

CanSat is basically used for educational and simulation purpose because of its development is very easy and cost efficient where bigger size satellite cost a lot for the development. CanSat subsystem is directly connected to its brain commonly called as onboard computer system (OBC) and compare to the other big satellite or the CubeSat, it's have independent subsystems, where each of subsystem have separate boards, likely CanSat have communication module and CubeSat have communication system.

CHAPTER 7
Ground Station

7.1 Introduction

The Ground Station is needed for both CubeSat and CanSat for the transmission and reception of data as well as for the testing and monitoring of their operation. It's also called as satellite control center. In this study, CubeSat and CanSat both are using SX1278 LoRa wireless transmission and receiving module which have 433MHz spread spectrum technology. For that reason, our ground station also consisting of a SX1278 LoRa wireless module for sending commands and receiving data from the CubeSat and CanSat.

7.2 Ground Station Block Diagram

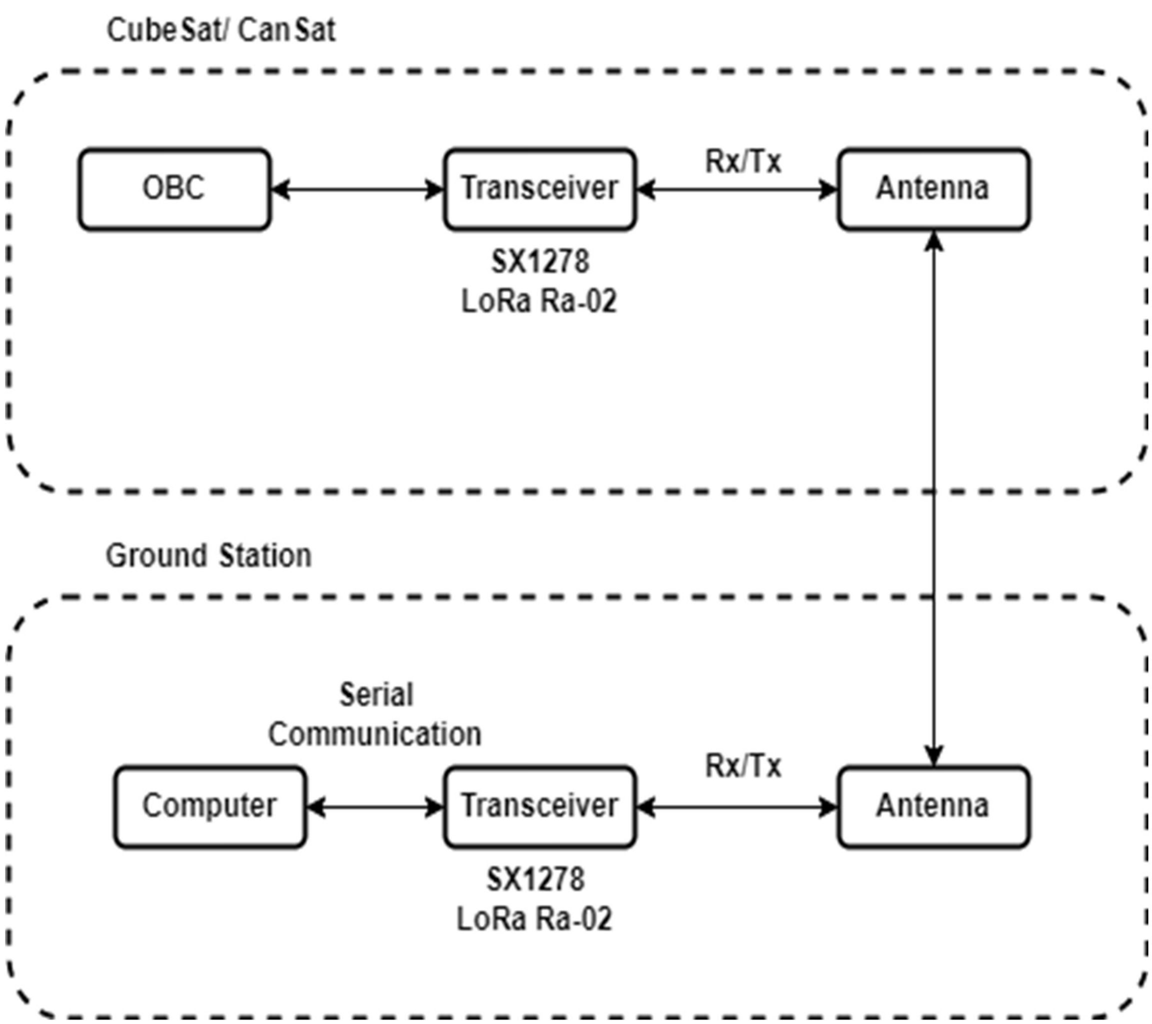


Figure 7.1: Ground Station Block Diagram

The main benefit of using LoRa communication is ultra-long range spread spectrum communication and high interference immunity whilst minimizing current consumption. In the above Figure 7.1 showing the communication block diagram of between Ground Station and CubeSat/CanSat.

7.3 Ground Station Transceiver

For the Ground Station, I use a SX1278 LoRa Ra-02 communication module, Arduino UNO and a computer. SX1278 LoRa Ra-02 received the signal from CubeSat/CanSat and after processing, we can monitor the current health of satellite through Arduino IDE serial monitor. In the below Figure 7.2 showing the interfacing between Arduino Uno and SX1278 LoRa Ra-02.

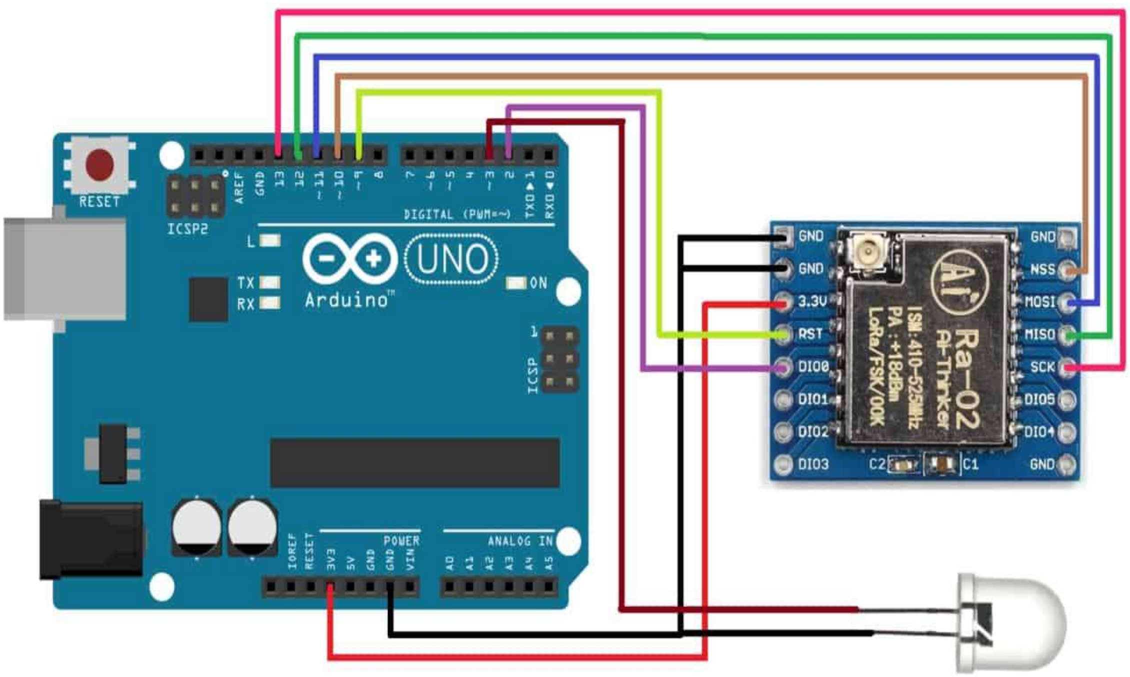


Figure 7.2: Ground Station Transceiver

7.4 Ground Station Signal Receiving and Testing

For testing the communication, firstly I write and upload transmission and receiving code to the CubeSat communication subsystem and also in my ground station end. The successful Signal Receiving and Testing result is given below Figure 7.3.

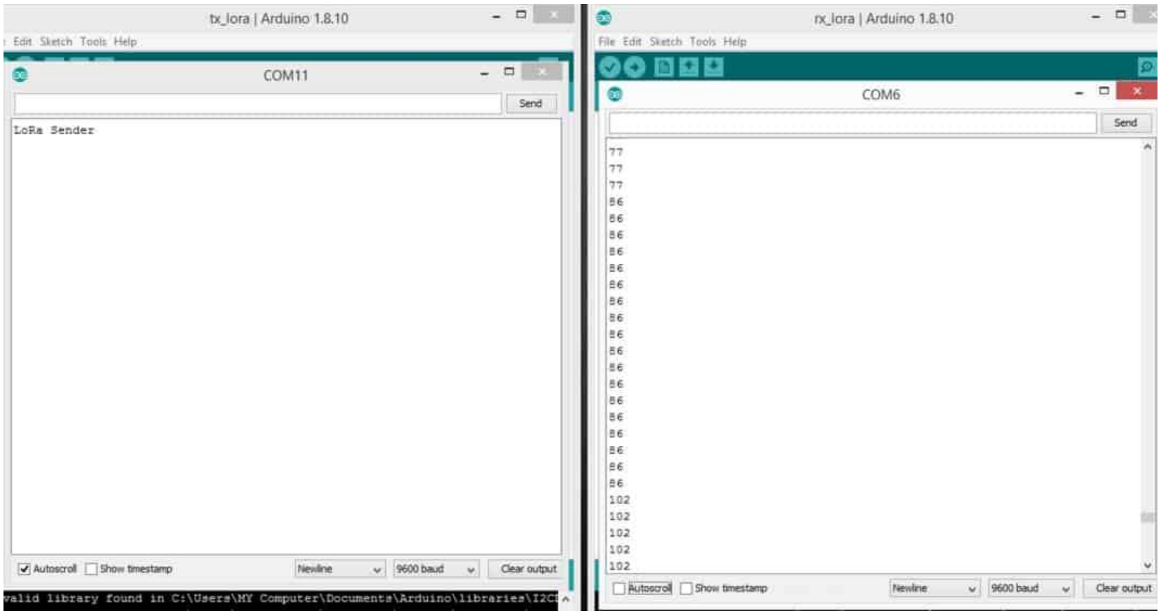


Figure 7.2: Ground Station Signal Receiving and Testing

7.5 Conclusion

In this chapter the CubeSat and CanSat subsystems is extensively analyzed and tested result is shown and discussed.

CHAPTER 8

Experimental Results and Discussion

8.1 Introduction

In this study, I developed a CubeSat and CanSat which is consist of some electrical subsystems and in this chapter discussed about these CubeSat and CanSat experimental results.

8.2 Experimental Setup

The CubeSat have electrical power system (EPS), attitude determination and control system (ADCS), onboard computer system (OBC) and communication system. And the CanSat also have the same of some system connected to onboard computer. But CanSat never leave the Earth atmosphere for that he did not needs safety from radiation.

I use Ansys for the CubeSat structural deformation, stress and natural frequency test. For getting others sensos data I use Arduino IDE serial monitor and cameras output. For checking the CubeSat Attitude Determination and Control System and visualize the data I use "Processing". In the below TABLE 8.1 showing the tools used in CubeSat experiments.

TABLE 8.1 : CubeSat Experimental Setup

No	Subsystem	Experimental Tools
1	Structure	Ansys
2	Electrical Power System (EPS)	Multimeter, Power Supply, Oscilloscope
3	Attitude Determination and Control System	Processing
4	On-board Computer System (OBC)	Putty
5	Communication System	Arduino IDE
6	Sensors	Arduino IDE

For experimenting CanSat system Arduino IDE and tools like multimeter, oscilloscope and tools box is used. In the below TABLE 8.2 showing the tools used in CanSat experiments.

TABLE 8.2 : CanSat Experimental Setup

No	Subsystem	Experimental Tools
1	Structure	Ansys
2	Electrical Power System (EPS)	Multimeter, Power Supply, Oscilloscope

3	Attitude Determination and Control System	Processing
4	On-board Computer System (OBC)	Arduino IDE
5	Communication System	Arduino IDE
6	Sensors	Arduino IDE

8.3 Experimental Results & Analysis

CubeSat structure consisting of top, bottom and legs and using Ansys I tested its structure stress, deformation and natural frequency as shown in below Figure 8.1, Figure 8.2, Figure 8.3 and Figure 8.4 and result in TABLE 8.3.

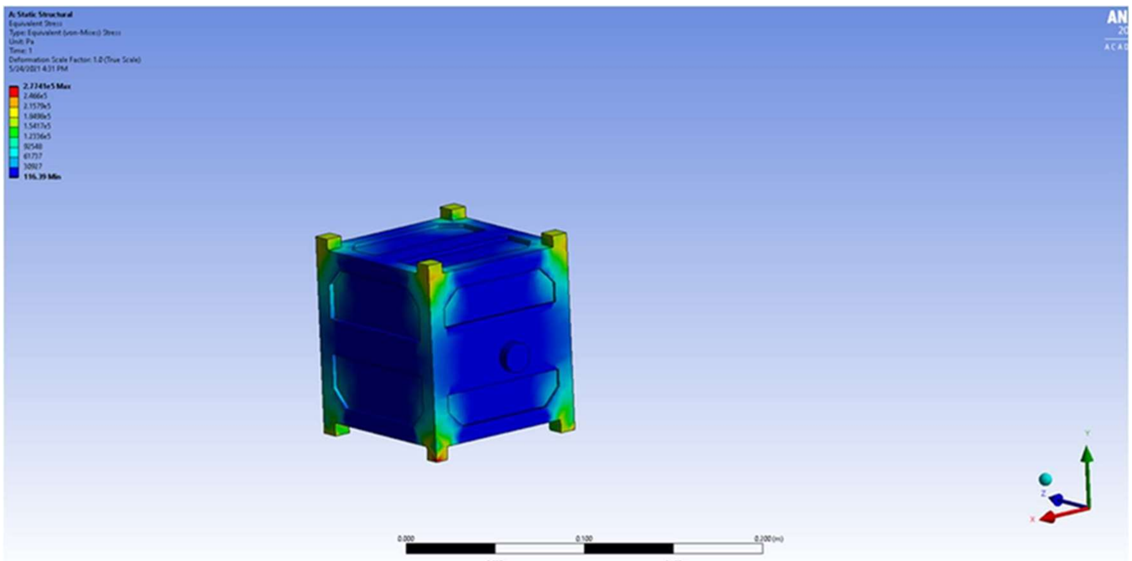


Figure 8.1: CubeSat Structure Stress and Deformation Test Case 1

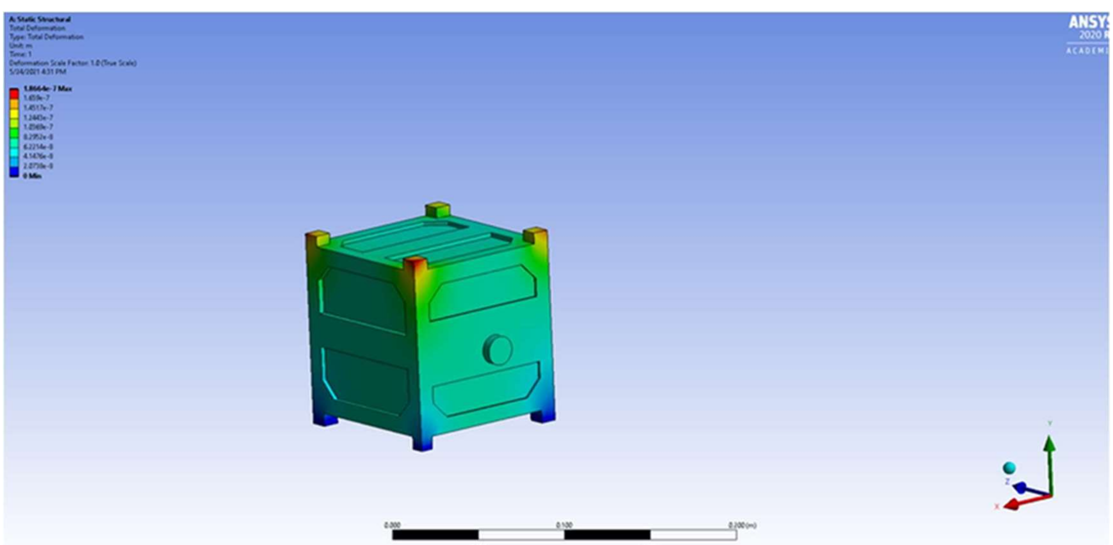


Figure 8.2: CubeSat Structure Stress and Deformation Test Case 2

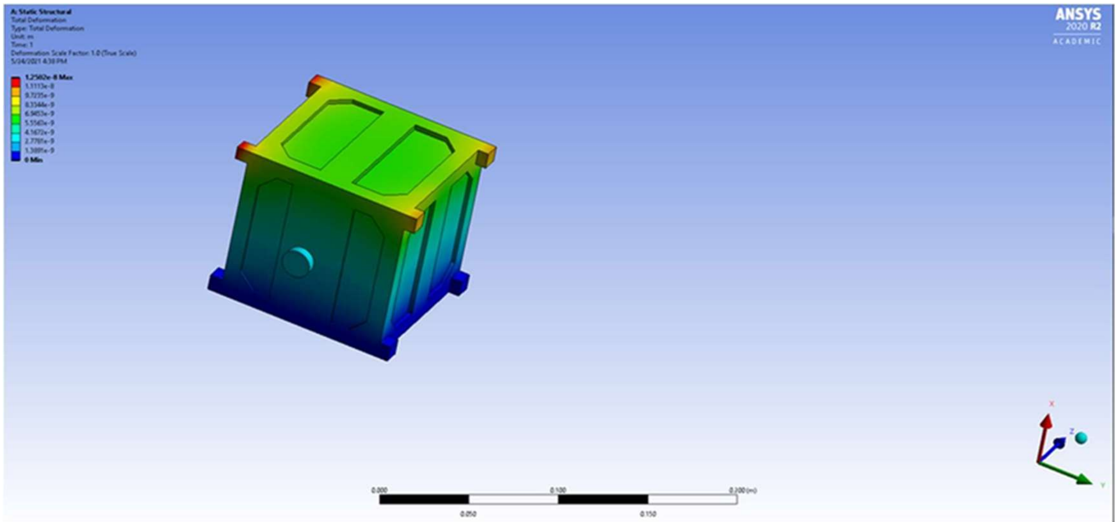


Figure 8.3: CubeSat Structure Stress and Deformation Test Case 3

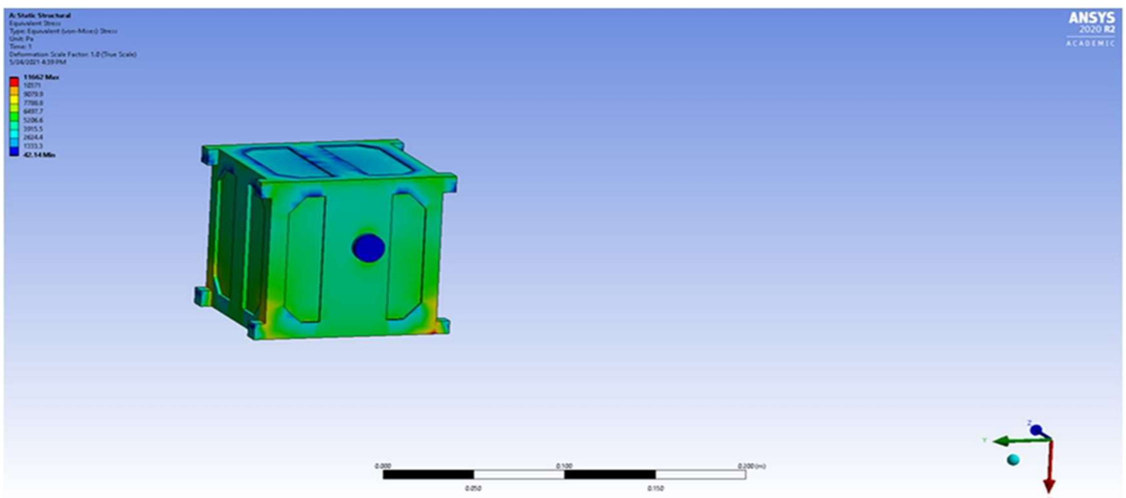


Figure 8.4: CubeSat Structure Stress and Deformation Test Case 4

TABLE 8.3 : CubeSat Structure Stress and Deformation

Test Case	Vertical Loading	
	Equivalent Stress (MPa)	Deformation (e-6m)
Case 1	2.774	1.866
Case 2	1.541	8.295
Case 3	1.233	4.147
Case 4	116.39	0
	Horizontal Loading	
Case 1	11662	1.250
Case 2	6497.7	6.945
Case 3	2624.6	2.778
Case 4	42.14	0

CubeSat structure natural frequency testing is given below Figure 8.5, Figure 8.6, Figure 8.7 and Figure 8.8 and results is shown in the TABLE 8.4.

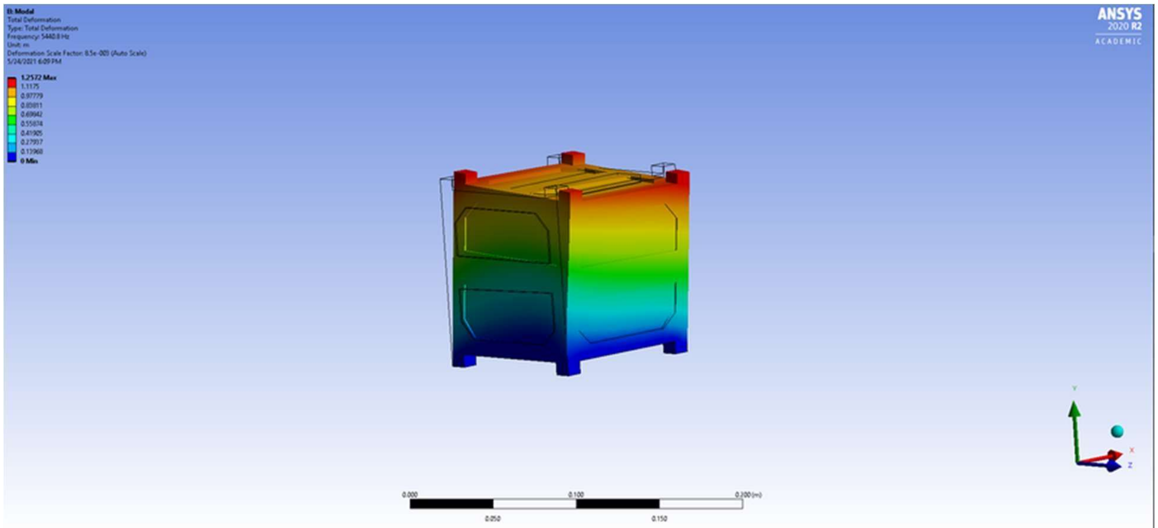


Figure 8.5: CubeSat Structure Natural Frequency Test

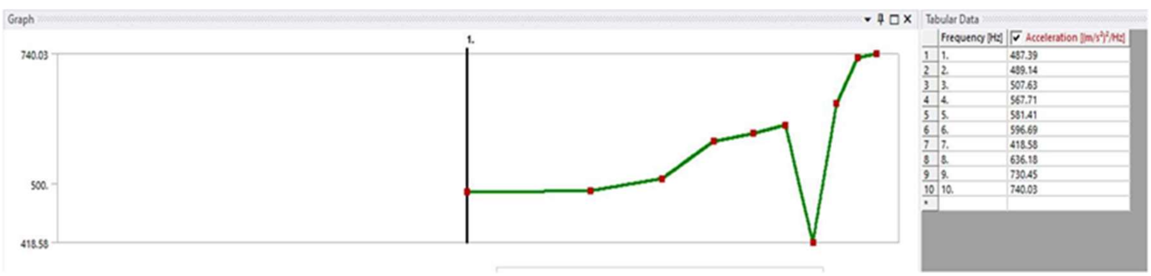


Figure 8.6: CubeSat Structure Applied Natural Frequency in X Axis

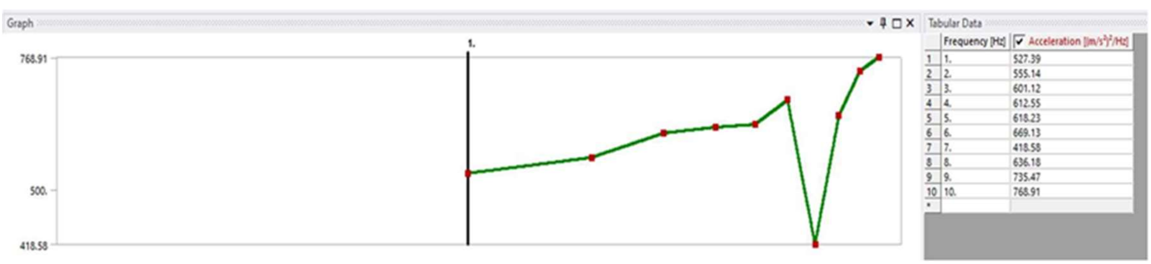


Figure 8.7: CubeSat Structure Applied Natural Frequency in Y Axis

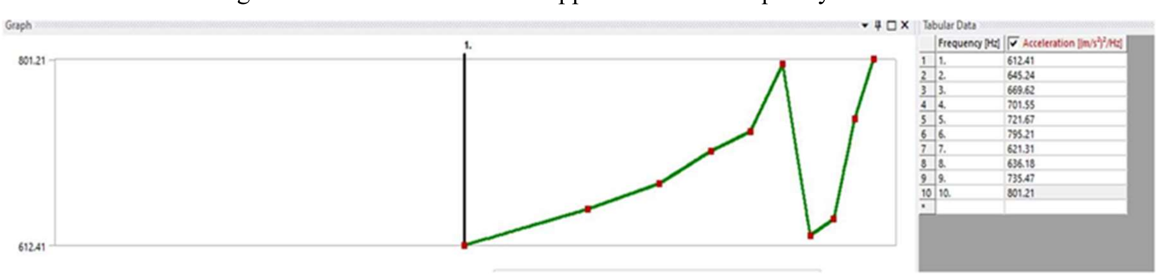


Figure 8.8: CubeSat Structure Applied Natural Frequency in Y Axis

TABLE 8.4 : CubeSat Structure Natural Frequency

Axis	NATURAL FREQUENCY [Hz]
X	452.92
Y	490.441
Z	563.719

CubeSat Attitude Determination and Control System (ADCS) is testing by “Processing” and its result showing in the below Figure 8.9. according to X,Y and Z axis its move and also showing the value of roll and pitch.

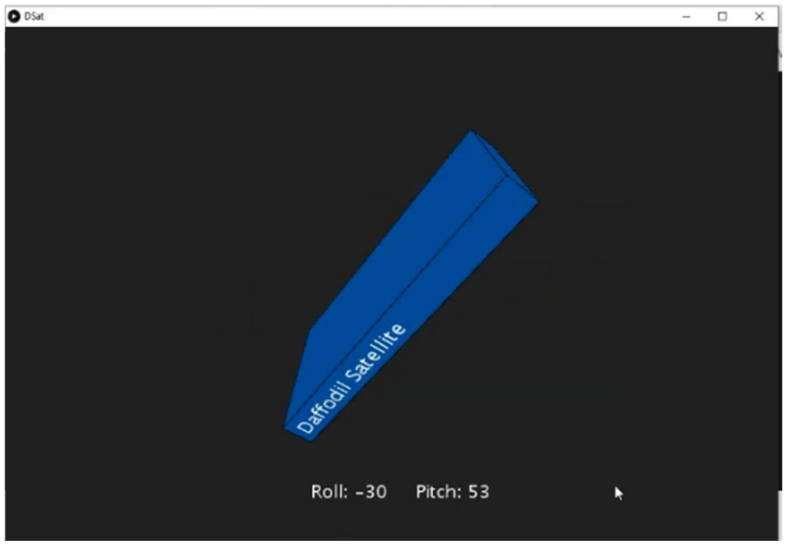


Figure 8.9: CubeSat Attitude Determination and Control System (ADCS) Test

Also, CubeSat and CanSat have some sensor system which data is received via Ground Station and sends it to “Thing Speak” cloud for the visual representation showed in below Figure 8.10.

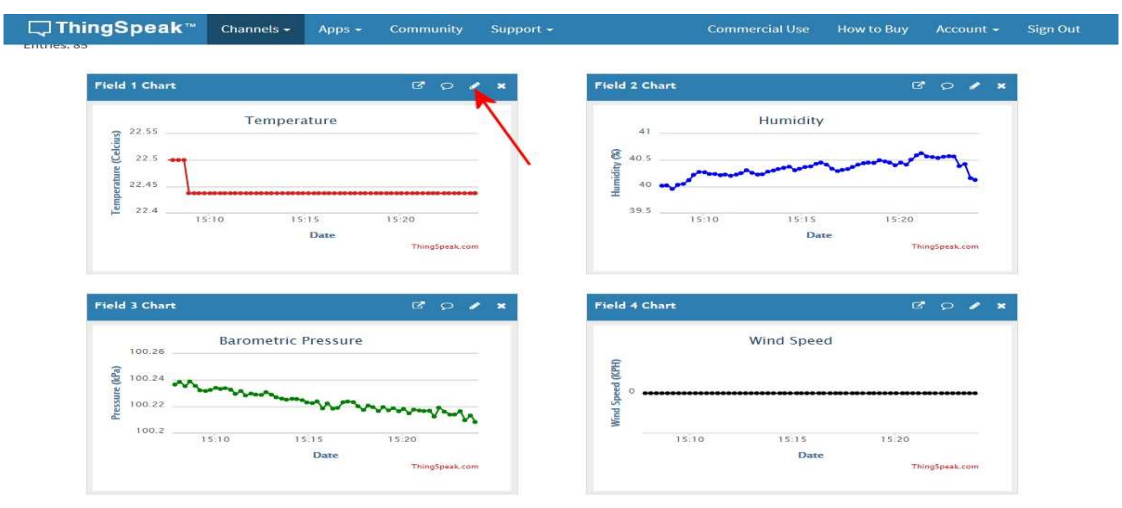


Figure 8.10: CubeSat and CanSat Sensors Data Representations

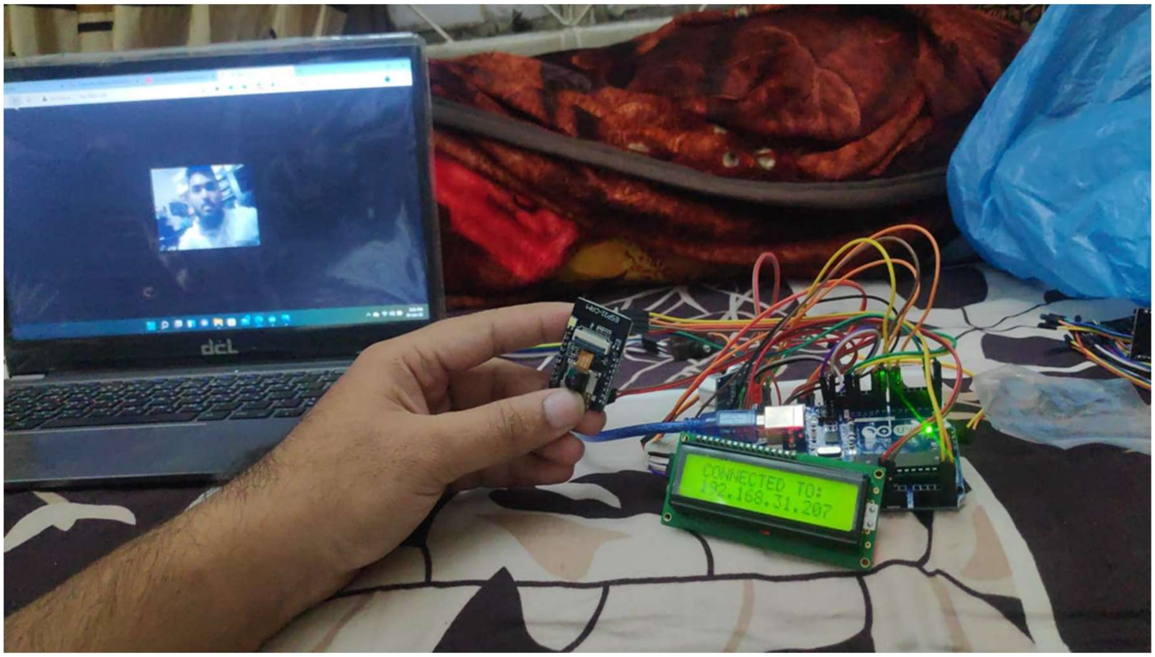


Figure 8.11: CubeSat and CanSat Camera System

In the above Figure 8.11 showing the result of camera system, that is capable of capturing picture and live telemetry. This camera system is connected to onboard computer system (OBC) in both CubeSat and CanSat subsystem.

In the below Figure 8.12 showing the receiving data that is coming from the transmitting module. I send some dummy data for checking and found that the both systems are working correctly.

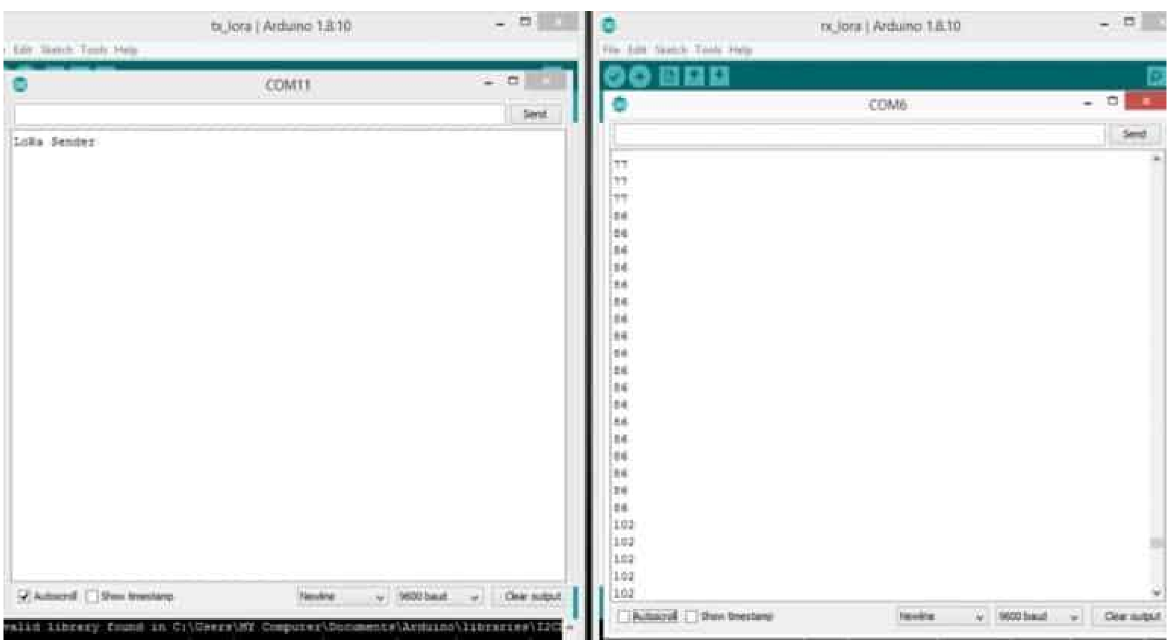


Figure 8.12 : CubeSat and CanSat Communication System Interfacing and Testing with Ground Station

8.4 Discussion

CubeSat and CanSat are class of nanosatellite which have gained a lot of popularity now a days. These satellites are emerging alternative to the big satellites for Earth explorations, weather updates or space program. In this study we built a CubeSat and CanSat which is mainly for weather updates and capturing picture from birds' eye view.

CHAPTER 9

Impact on Society, Environment and Sustainability

9.1 Introduction

CubeSat and CanSat are making huge significant and positive changes in our society that solves many problems or at least address the education or research purpose satellite development by reducing costs and availability of resource. CubeSat or nanosatellites orbital lifetime in low Earth orbit is not more than 25 years [89]. And the sustainability of CubeSat depending on its drag coefficient that's are proportional, if the drag coefficient increases its lifetime decrease [90].

9.2 Impact on Society

Social and economic activities are the very common in every society. Economic activities are affects and shaped by social process and positive affect increase the improvement in society. Modern societies progress, stagnate, or regress are depending of their local or regional economy.

Satellites are also used to provide broadcasting services radio and television. For distributing these multi-channel radio or television programs to the consumer direct-to-home (DTH) services are used. This system helps us to know more about the other's culture and traditions.

To communicate with people all over the world, satellites are helping us to provide internet connectivity in rural or remote areas. By facilitating the communication system of the remote areas and connecting them to the global village, it is playing a major role in the development of the education system and culture of those areas.

For decision-making and planning in business, communication is the most important thing and readily available communication also helps a society's growth. Satellite communications are very versatile and have a big impact on emerging economies, providing services that drive rapid growth. Also, it makes remote areas less remote and also grows those areas' education and culture.

Also, earth observation satellite helps society by giving advanced weather updates. With these updates, ships and airplanes are operating their daily schedules. This type of

miniature satellite or CubeSat which is used for earth observation or weather updates plays an important role in keeping the economic system of a society functioning.
CubeSat and CanSat also help to develop, simulate and test satellite engineers' society at a lower cost for educational or research purposes. Which will play a revolutionary role in making big satellites.

9.3 Impact on Environment

Environment actually refers to the surroundings or conditions in which a person, objects or machines. In this study, there are two types of environments. Where satellite will operate and where people will avail the service given by the satellite.
High Earth orbit, medium Earth orbit and low Earth orbit are the three types of earth orbit where satellites are mainly orbiting the earth for many purposes like earth observation, weather and atmosphere monitoring, communication purpose, and navigation purpose. The far away from the earth is High Earth orbit, then medium Earth orbit and then lower. When satellites stop working, they may mark as "space debris". Sooner or later, though, the force of gravity will pull all objects, including artificial satellites, back to Earth. Although at least one piece of space debris returns to Earth every day, it is rarely noticed [91].

Figure 9.1: One way of classifying orbits is by altitude [92]

So, impacts on earth orbit by a satellite are already discussed. But the impact on the earth's environment where people will avail of the service given by the satellite is described below.
Climatic disasters are widespread nowadays; floods, storms, droughts, and heat waves have been rising worldwide. Also, the rising concentration of greenhouse gases will cause

terrible disasters [93]. The atmosphere, and temperatures, on average, have been rising and these also have a huge impact on our agriculture and industries. So, we cannot prevent these types of natural disaster issues, but we can still alert the affecting areas to prevent large casualties or corrosion damage. Here, satellites are playing a vital role by predicting weather patterns and updating us in advance which helps us to reduce the damage.

Due to CubeSat, CanSat or best usage of any other miniature satellites and through that satellite we can able to protect our environment from natural disasters or other risks. Because the environment plays a key role in our economy. A stable environment gives us a stable economy that will help us as a direct input into production and through the many services it provides.

9.4 Ethical Aspects

CubeSat and CanSat are miniature satellite that very easy to developed and needs very low budget. According to dealing with morals, these CubeSat, CanSat or other miniature satellite only used for earth exploration, educational or research purpose. But there are some unidentified satellites exists in earth orbit, which are called “SPY satellite” [94-97]. Satellite is also used for military purpose. And in the race of becoming superpower some country used this type of spy satellite to steal the secret information of their competitor country. This type of spy satellite also called as reconnaissance satellite and they are used as other common satellite but they are very precise and intelligent [98]. Natural disaster response and humanitarian missions this type of satellite can give advantage.

Initially, satellite observation technology was controlled by several government agencies. However, as the technology develops and is used by more and more private companies, the risk of misuse of the technology increases significantly. Some of the risks of misuse of satellite observation technology include industrial espionage, illegal espionage against commercial competitors and nations, and theft of classified information [99].

9.5 Sustainability Plan

In this section describes the CubeSat, CanSat or miniature satellite operational and management strategies to continue the CubeSat or CanSat services to integrate the full operation.

Earth orbits the sun and its intercepts a lot of solar power. In Earth's orbit, the only power source we can use is solar power. In chapter 5 as I already discussed how CubeSat or CanSat can power up through its Electrical Power System (EPS). Electrical Power System (EPS) is generally used to charge the Li-Polymer batteries and also distribute a stable power supply to all subsystems. Using solar energy makes the full system sustainable cause we can get unlimited power from solar energy.

Attitude Determination and Control System – ADCS subsystem is mainly worked as the stability control and controlling roll, yaw and pitch of the full system. The inertia measurement unit (IMU) is basically placed in this system. When satellites orbit the Earth, due to gravity sometimes lost their direction. For controlling its movement and direction ADCS or Attitude Determination and Control System are used.

The onboard computer system is used as the brain of the system. For any kind of decision-making, this system is used. Also, data processing, sending and receiving data through a communication system this system plays a vital part.

The combinations of Flight computers, Navigation, Communications, and Antenna subsystems make the full system sustainable.

CHAPTER 10

Summary, Conclusion, Recommendation and Implication for Future Research

10.1 Summary of the Study

The systems of CubeSat and CanSat are quite different and flexible in this era if I analyze with other related work on it. Normally, CubeSat or CanSat subsystems are divided into many parts, like Electronics Power Systems, Communications Systems, Antenna Systems, On-board computer systems, Flight Computer and Software Systems, Camera, Batteries and other sensors. With different subsystems, I can say that every system has the capabilities to compete with previous systems. The CubeSat and CanSat emerging alternatives to conventional satellites. For educational and research purposes this type of satellite can be revolutionary. When comes to development costs bigger size satellites can cost a lot. Whereas CubeSat and CanSat can be made from scratch or from very cost-efficient equipment.

10.2 Conclusions

Big satellite has always been constructed by large companies and government organizations but for education and research purpose these satellites are very costly. Weather forecasting, radio and television program streaming, navigation and internet satellite are broadly used for earth exploration and in this field nano class satellite like CubeSat can be new opportunity. CanSat never leave the Earth atmosphere and never orbiting the Earth. This Can shaped satellite only used for educational and study purpose. CubeSat and CanSat are miniature satellites mainly used by educational or research-based institutes for the development or simulation for practicing whereas big-size satellite development costs a lot. The main purpose of this study is to develop and demonstrate the CubeSat and CanSat also study their internal subsystem. Experimental result is also showed and discussed.

10.3 Implication for Further Study

The CubeSat is a class of nanosatellite which have multiple area of research. In this study only discussed about the basic subsystems of the CubeSat. In this modern era technology are updating every day and new types of processors, sensors and many other electronics ae coming to the market every day. Reaction wheel o CubeSat thruster system should be developed in the future. Also, in space research industry need a good power system to increase it lifetime.

The CanSat is used for the simulation and education purpose. "Can" referring to a drink "can" and "Sat" which is the short form of the word "satellite". It provides a developer, researcher with an opportunity to experience the design life-cycle of an aerospace system as well as the behind its computer science and electrical engineering also involved to build a CanSat. The launching system of CanSat still now in ancient. Need more studies to improve its launching and comeback operations.

Ground Station also an important part of satellite communication, control and mission operation. Need more developed satellite ground station for towards the future research. NASA Operational Simulation for Small Satellites (NOS) is a satellite simulation software that is developed by NASA engineers which help us to simulate nano CubeSat simulations.

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