

DESIGN OF A 3U SATELLITE: BARQNA 786 ON CUBESAT DESIGN SPECIFICATIONS

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Abstract—Barqna 786 is the Spacecraft Dynamics and Control project at Institute of Space Technology, Islamabad, Pakistan. The aim of the satellite is to give a chance to the graduating students of Department of Aeronautics & Astronautics to get familiar with the workings of satellites and therefore on the design specifications of CubeSat program, small satellites have been being designed. Barqna 786 is unique in the aspects of having military and research benefits to Pakistan along with equipping students of insight into the satellite designing. This paper highlights the features and capabilities of Barqna 786, including experiments related to gathering of ocean and land data near Pakistan's coast, GPS-based position determination and, reaction wheel and mini-ion thrusters for attitude control.

1. Introduction

Barqna 786 is the Spacecraft Dynamics & Controls small satellite project at Institute of Space Technology (IST) Islamabad, Pakistan. It is based on the CubeSat program started by Stanford University and California Polytechnic State University (CalPoly)^[1]. The primary goal of the CubeSat program is to provide students the opportunity to develop complete satellite systems and get hands on experience with space-based experiments using relatively inexpensive satellites. The Barqna 786 is a 3U satellite with a volume of 3000cm³ and maximum mass of 4.33kg. The objective of Barqna 786 is to gather data regarding sea surface temperature, ocean winds and moisture content over land and sea using Ultra Compact Microwave Radiometer. The constraints set forth before the design phase initiated were, it has to have benefits for Pakistan, must be cheaper than a Corolla Altis (PKR 2,100,000) and has to follow the CubeSat design specifications & P-POD deployer specifications. The satellite has been designed keeping in view the 3U capacity of a P-POD deployer. Barqna 786 will be making use of GPS and Solar cells to determine its attitude and, reaction wheels and mini-ion thrusters are used for controlling the attitude and orientation of the satellite.

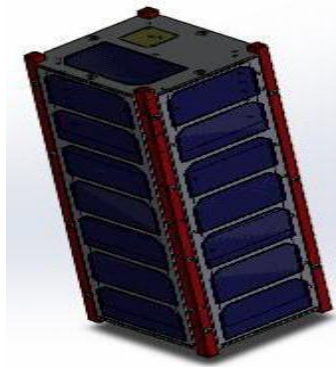


Figure 1: 3D CAD model (collapsed) of Barqna -786 (designed on Solidworks 2014)

2. DESIGN

2.1 PAYLOAD

The selected payload is Ultra Compact Microwave Radiometer which would collect data on sea surface temperature, ocean winds and moisture content over land and sea.

The benefits to Pakistan of using such a payload are:

- Benefits to navy (measurement of humidity and sea surface temperature)
- Benefits to Meteorological Department of Pakistan (Ocean winds and Moisture content over land and sea, along the coast)

The table below summarizes the payload details:

Table 1: Payload Details

CubeSat name	<i>Barqna 786</i>
Cubesat type	<i>3U</i>
Payload	<i>Ultra Compact Microwave Radiometer</i>
Tentative Mass (Payload)	<i>500g</i>
Tentative Volume (Payload)	<i>1000 cm³</i>

2.2 ORBIT

The Barqna 786 orbital analysis is based on a circular Medium Earth Orbit with a time period of 2hrs. The satellite would pass over the coastal line of Pakistan 12 times a day with a total passing time over 24 hrs equaling to 30 minutes, out of which 20 minutes will be allocated for collection of data and 10 minutes allocated for the transmission of it^[2].

The orbit details are listed in the following table:

Table 2: Orbit Details

Time Period (hrs)	2
Radius (km)	8058.994
Altitude	1680.894
Inclination (degrees)	3.049
Data Collection (time)	02:00 – 16:00
Data Transmission (time)	18:00 – 00:00
No. Of orbits in a day	12
Frequency over Pakistan (Hz)	1.38910^{-4}

3. ATTITUDE AND ORBIT CONTROL

3.1 ATTITUDE DETERMINATION

Global Positioning System (GPS) is used for finding the attitude of the satellite at various instants and this information is fed to the On Board Computer (OBC) for further operations. Solar cells are present and light incident on them generates a voltage which is compared by the OBC for right orientation of the satellite. The instant when the satellite is over the target location has a particular intensity of Sun's light falling on to it and it is used to correct any orientation errors.

3.2 ATTITUDE CONTROL

Reaction wheels and Mini-Ion thrusters are used for controlling the attitude of the satellite. Reaction wheels generate less torque and are efficient in small attitude changes. Mini-ion thrusters are used mainly for correcting the 30° phase lag due to rotation of Earth after every 2hrs. Therefore, the mini-ion thrusters have to be used to correct for the 30° phase angle, covering a ground track of **4230.972 km** over the next 2hrs after the last target encounter.

4. OBC, COMMUNICATION & DATA HANDLING

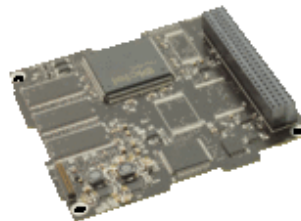


Figure 2: OBC

OBC is purchased from clyde space, which acts as the controller of the whole cubesat system. It integrates all the subsystems of the cubesat including communication and telemetry^[3]. Communication and data handling is done using combination of the electrical power system, on board computer and the payload antenna. Also GPS system sends the relative information required to maintain the positioning of the satellite. Figure 3 shows the block diagram of the whole system, highlighting how one-way and two-way communication goes on between the modules in the system.

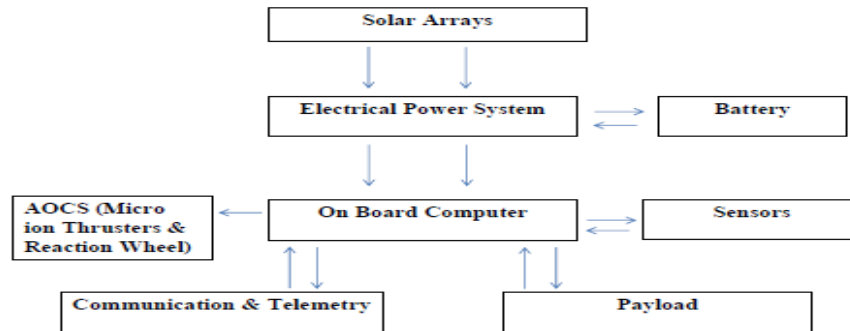


Figure 3: System Block Diagram

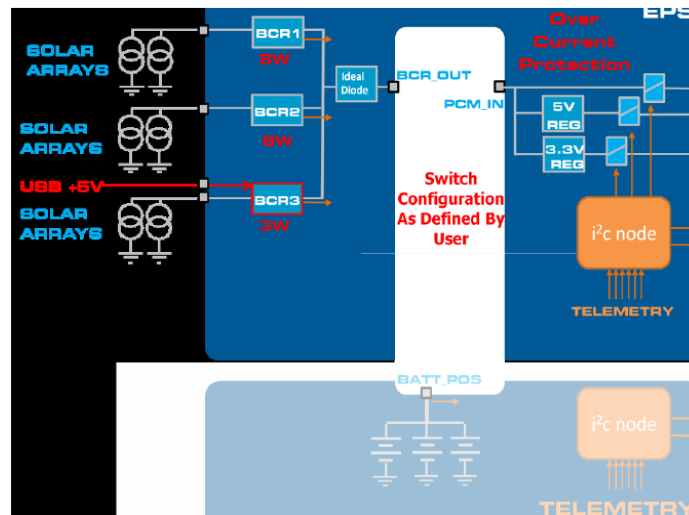


Figure 4: Detailed Electrical Power System

Electrical Power Subsystem (EPS) consists of four subunits; power source includes solar cells or batteries, then a storage unit, cabling is then required to transmit the power while providing shock-protection and finally has to regulate and control the power, save from overheating and overcharging. i^2c node provides communication link between integrated circuits^[4].

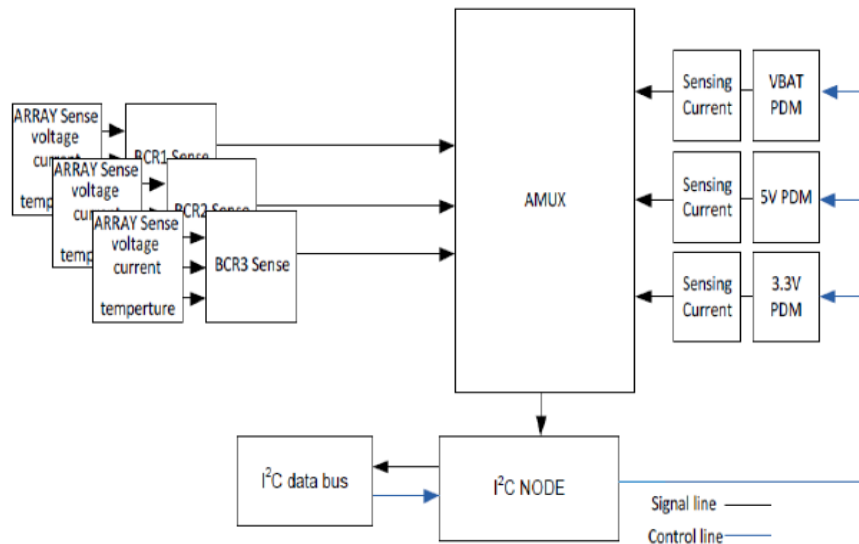


Figure 5: Telemetry

Analogue Multiplexer: A 32 channel analogue multiplexer is used for selecting the correct sensor signal. The multiplexer is controlled from the microcontroller.

Further Hardware: Further required hardware includes an oscillator and an I2C bus extender. The oscillator provides a robust clock signal for the microcontroller. The bus extender provides greater robustness to signal noise on the I²C bus during integration and operations.

The I²C Node is based on the Microchip PIC16F690. The device node is configured to act as a single channel analogue to digital converter. The microcontroller controls the analogue multiplexer that routes the signals from the sensors. The PIC16F690 program is designed to operate as a slave sensor node on the i²c bus. The program will select and then convert the desired signal data from the telemetry network on demand. There is also a control feature that can briefly shutdown PDMs within the EPS.

5. BATTERY

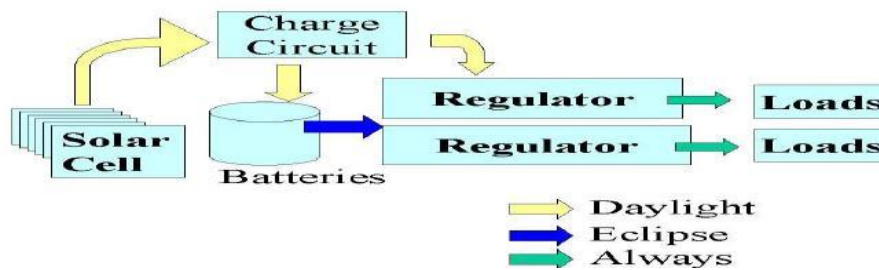


Figure 6: Working of Battery

During the time Sun is incident on the solar cells the energy is provided through the regulator to the OBC and through it to the other components. When the satellite is out of Sun's illuminated range, the batteries that had been storing energy are used to power the OBC. Therefore, OBC has a continuous supply of energy to carry out its desired tasks.

6. CONCLUSION

The design specifications of Barqna 786 have been set and the required equipments are being procured. Barqna 786 will be a valuable addition to the Institute of Space Technology's student satellite space programs for Pakistan.

In near future the satellite will be subjected to tests involving electromagnetic interferences and structural integrity. The satellite will be part of the P-POD deployer of China's space mission to be launched by December 2014.

7. ACKNOWLEDGEMENT

The authors would like to thank Institute of Space Technology, Islamabad, Pakistan for assisting with the project and letting access to its CubeSat facility. The authors would finally like to thank their advisor for the project, Miss Zainab Saleem for her help, patience and morale boosting efforts.

8. REFERENCES

[1] Puig-Suari, J., Turner, C., Twiggs, R.J.

CubeSat: The Development and Launch Support Infrastructure for Eighteen Different Satellite Customers on OneLaunch, Proc. 15th Annual AIAA/USU Conference on Small Satellites, Logan, Utah, 2001.

[2] Larson, W. J. and Wertz, J. R., Space Mission Analysis and Design, 3rd ed., Kluwer Academic Publishers, Dordrecht, Holland, 1999

[3] <http://www.clyde-space.com>

[4] <http://en.wikipedia.org>

APPENDIX A: ORBIT

Type: Medium Earth Orbit (Circular)

Time Period = 2hrs (7200s)

Semi major axis (a) = 8058.994 km = Semi Major axis (b)

Altitude = 1680.894 km

Angular Velocity = 8.727×10^{-4} rad/s

Centripetal Force = Gravitational Force = 24.551 N

Inclination = 3.049°

1.1 Orbit Schedule:

Time	Task To Do
00:00	Start of Orbit(initially)/ Data Transmission
02:00	Data Collection
04:00	Data Collection
06:00	Data Collection
08:00	Data Collection
10:00	Data Collection
12:00	Data Collection
14:00	Data Collection
16:00	Data Collection
18:00	Data Transmission
20:00	Data Transmission
22:00	Data Transmission
00:00	Data Transmission

Distance travelled = $2\pi r$ (Orbit Circumference) = 50636.153 km

Velocity = 7.033 km/s

Pakistan coastal line = 1050 km

Time duration over coastal line of Pakistan = 149.296 s (8 times for data collection, and 4 times for data transmission)

Time for Data collection = 8×2.50 minutes = 20 minutes per day

Time for Data Transmission = 4×2.50 minutes = 10 minutes per day

1.2 Distance between Adjacent Ground Tracks:

Rotation of Earth = 7.29212×10^{-5} rad/s

After 2 hours, Earth Rotates = 0.525 rad = 30° , hence our satellite will be having a phase angle of 30° , after it completes one orbit and comes back above Karachi, from where it started initially.

This distance is calculated by $s=r\theta$:

$$s = (8058.994 \text{ km}) \times (0.525 \text{ rad})$$

$$s = 4230.972 \text{ km}$$

Hence $\Delta L = 4230.972 \text{ km}$

The phase lag of 30° will be covered within next orbit of 2 hours each time using Mini (ion) thrusters and Reaction Wheel Assembly.

1.3 Number of Orbit in Days:

12 orbits each day

1.4 Frequency over Pakistan:

Mini Ion Thrusters and Reaction Wheel Assembly, allow it to pass 12 times per day over Karachi, Pakistan i.e. 12 times per 86400 seconds (for 2.50 minutes each time) therefore: frequency(F)= 1.389×10^{-4} Hz

Low Earth Orbit was initially selected:

- **Low Earth Orbit:** (Not Selected)
It was thought to be selected for better communication (reading and transmission of data), due to shorter altitude. But our time passage over coastal line would have been very less, since due to smaller altitude we have smaller Time Period and hence a lesser time for reading and transmission of result.
- **Medium Earth Orbit:** (*Selected*)
A possible compensation for LEO, since communication and data recording and transmission is better at this range. Allows for sufficient time over coastal region of Pakistan.

Reverse Engineering (for an optimum compensation)

Orbit Scheduling is done initially, and we want our satellite to have a particular Time Period (T).

For T= 12 hrs; (Not Selected)

Supposing our cubesat wants to meet Karachi twice in a day (once for data collection & once for data transmission)

$a = 26610.213$ km; altitude = 20232.11 km (High Earth Orbit);

Earth Rotates 180° (π radians) in 12 hours, $\Delta L = 83598.45$ km

Comment: Almost Impossible to meet Karachi twice, since mini ion thrusters are not strong to deviate the satellite π radians in radial direction (83598.45 km linearly). Even if we are able to propel it (somehow) for a distance of 83598.45 km in 12 hours with a velocity = 3.87 km/s, we don't get ample time to read and transmit data.

Time for passing over Karachi = 4.52 minutes (each time), i.e. 4.52 minutes at 12:00 hours for data recording and 4.52 minutes at 00:00 hours for transmitting. Also, since we are measuring the humidity, ocean wind paths and temperature readings, we need a continuous log file for a particular time interval, and lower altitude for accuracy.

Therefore by judgment and intuition Time Period (T) is lowered to T= 4hrs

For T= 4 hrs; (Not Selected)

$a = 12792.86$ km; altitude = 6414.756 km;

Earth Rotates 60° (1.047 radians) each 4 hours, $\Delta L = 13396.65$ km

Comment: Although a feasible altitude for better accuracy. But propelling the satellite for a linear distance of 13396.65 km within 4 hours for next meeting seems a hindrance in design. Again, if somehow propelled to meet Karachi 6 times a day with a velocity = 5.58 km/s, Time for passing over Karachi = 3.14 minutes (each time), hence $3.14 \times 3 = 9.42$ minutes for data recording & $3.14 \times 3 = 9.42$ minutes for transmitting (since satellite passes 6 times in a day, 3times data recording, 3 times data transmitting). The time for data transmission and data recording is very less.

Therefore, Time Period is thought to be further reduced, T= 2 hours.

For T= 2 hrs; (Selected)

$a = 8058.994$ km; altitude = 1680.894 km;

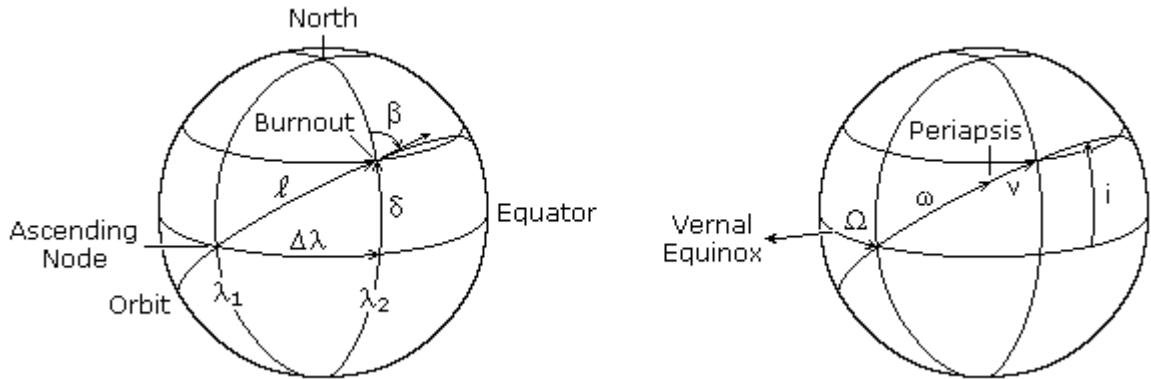
Earth Rotates 30° (0.525 radians) each 2 hours, $\Delta L = 4230.972$ km

Comment: A very feasible altitude, lying in the range of Medium Earth Orbits. Propelling the satellite to cover a phase lag of 30° seems quit feasible using Mini ion thrusters and Reaction Wheel Assembly. Orbit Scheduling is done to meet Karachi after every 2 hours using the thrusters to cover the distance of 4230.972 km. With a Velocity = 7.033 km/s, Time for passing over Karachi = 2.50 minutes (each time). Since satellite will pass 12 times over Pakistan coastal line, $8 \times 2.50 = 20$ minutes for data recording (out of 12 passing occasions, data recording will be done 8 times), $4 \times 2.50 = 10$ minutes for data transmission (data transmission will be done 4 times in a day). Time for data transmission and recording and the altitude seem satisfactory for a time peri-

od of 2 hours, also with continuous data recording payload performance will be much more efficient.

Inclination & Perturbation Calculations:

From: <http://www.braeunig.us/space/orbmech.htm>



$$\cos i = \cos \delta \sin \beta$$

SLV launch site = Xichang China (27.8992° N, 102.2700° E)

To be Deployed above Karachi (24.8508° N, 67.0181° E)

$$\cos(i) = \cos(\delta) \sin(\beta)$$

$$\delta = 27.8992 - 24.8508 = 3.049^\circ = 0.0532 \text{ radians}$$

$$\beta = 90^\circ = \pi/2 \text{ radians.}$$

$$i = 3.049^\circ = 0.0532 \text{ radians}$$

Perturbations For Circular Orbits:

Longitude of ascending node

$$\Omega_{\text{moon}} = -0.00338 \cos(i)/n$$

$$\Omega_{\text{sun}} = -0.00154 \cos(i)/n$$

$$\Omega_{\text{moon}} = -2.813 \times 10^{-4} \text{ deg/day}$$

$$\Omega_{\text{sun}} = -1.282 \times 10^{-4} \text{ deg/day}$$

Argument of perigee/ apogee/ semi major axis :

$$\omega_{\text{moon}} = 0.00169(4 - 5 \sin^2 i) / n$$

$$\omega_{\text{sun}} = 0.00077(4 - 5 \sin^2 i) / n$$

$$\omega_{\text{moon}} = 5.613 \times 10^{-4} \text{ deg/day}$$

$$\omega_{\text{sun}} = 2.558 \times 10^{-4} \text{ deg/day}$$

Perturbations due to nonspherical Earth:

$$\Omega_{J_2} = -1.5nJ_2(R_E/a)^2(\cos i)(1-e^2)^{-2}$$

$$\approx -2.06474 \times 10^{14} a^{-7/2}(\cos i)(1-e^2)^{-2}$$

$$\omega_{J_2} = 0.75nJ_2(R_E/a)^2(4-5\sin^2 i)(1-e^2)^{-2}$$

$$\approx 1.03237 \times 10^{14} a^{-7/2}(4-5\sin^2 i)(1-e^2)^{-2}$$

$$\Omega_{J_2} = -0.012 \text{ deg / day}$$

$$\omega_{J_2} = 0.0243 \text{ deg / day}$$

APPENDIX B: ATTITUDE AND ORBIT CONTROL SYSTEM

Reaction wheels and mini ion thrusters are used for Attitude & Orbit Control, along with their necessary circuitry, their connection to the OBC and with sensors such as GPS and solar cells are used for attitude sensing.

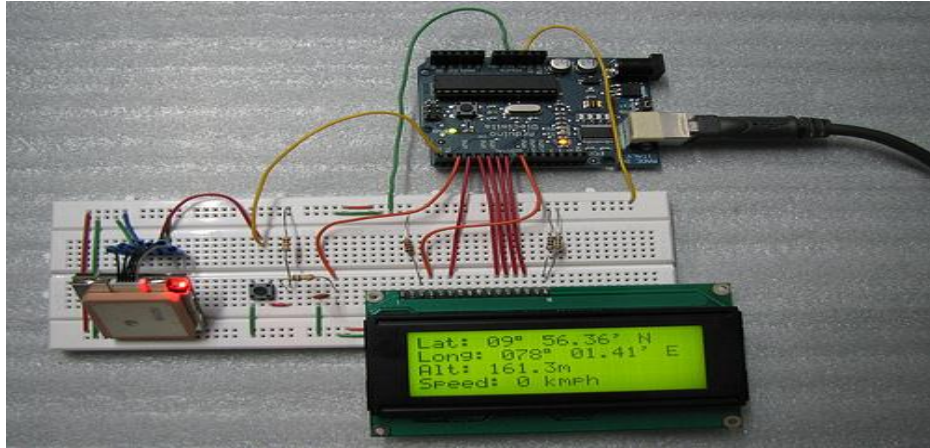


Figure 6: GPS

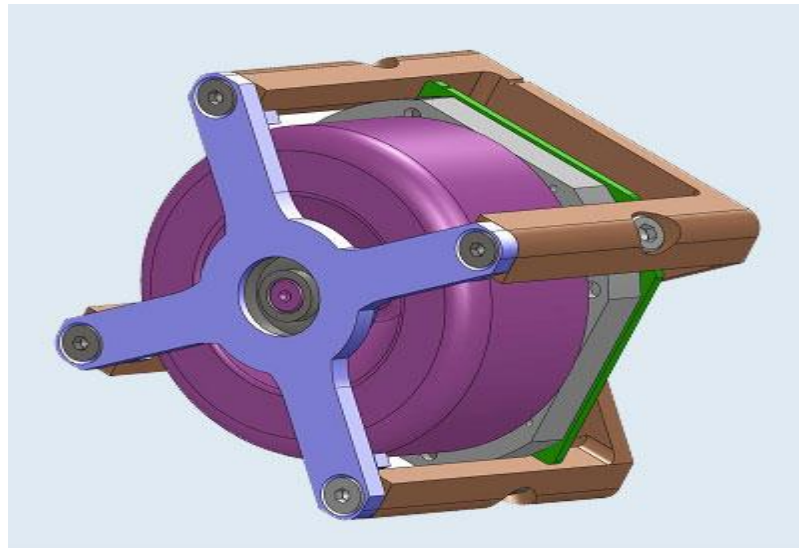


Figure 7: Reaction Wheel (Designed on Solid Works 2014)

APPENDIX C: 3D CAD MODEL

3D detailed CAD modelling for the cubesat was designed on Solid Works 2014.

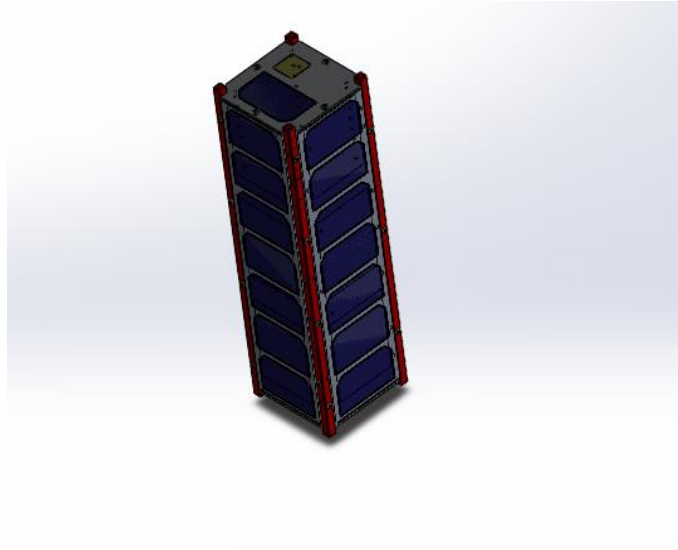


Figure 8: 3U CubeSat (Collapsed)

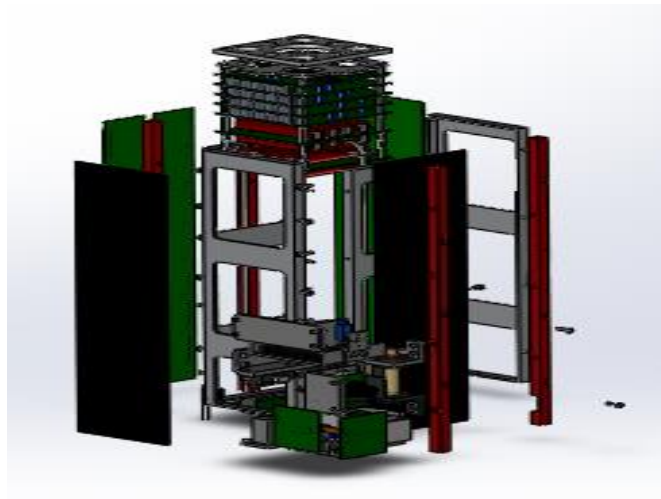


Figure 9: Exploded View of Barqna 786

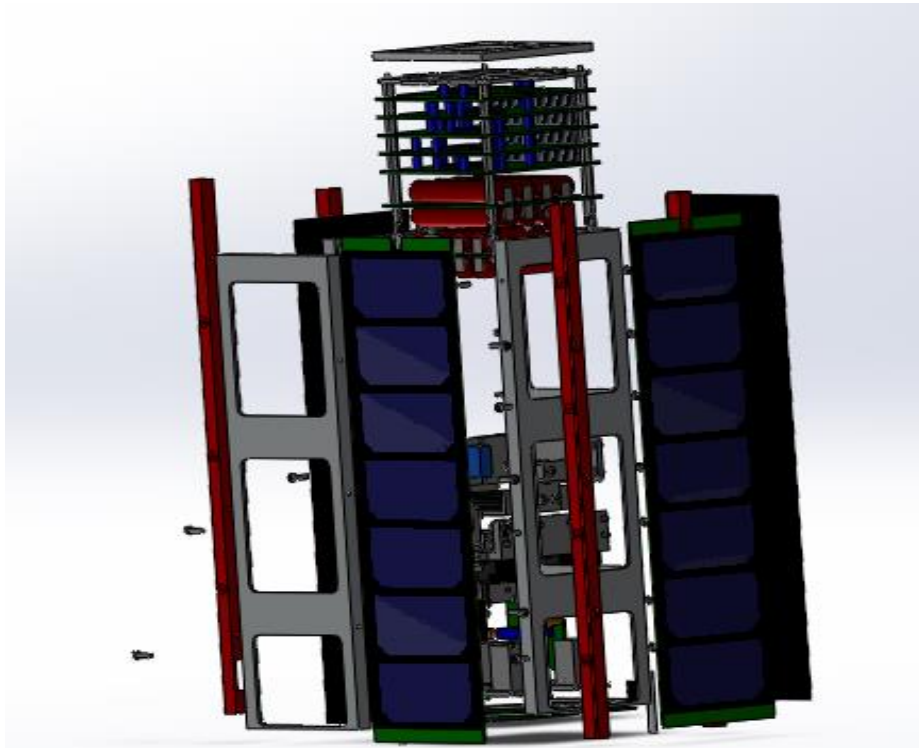


Figure 10: Exploded View of 3U CubeSat Barqna 786