Institute of Space Technology CubeSat: ICUBE-1 Subsystem Analysis and Design

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Abstract—For a long while, launching satellites for the purpose of research and technology demonstration largely remained with national space agencies and government organizations as the huge funding requirements inhibited the initiation of such projects at university level. It was this idea of providing, at university level, cheap access to space that prompted the design of miniaturized versions of satellites for research purposes. Specifications of CubeSat, a pico-satellite, were defined to provide easy access to space for educational and research institutions. The improvement in engineering technologies and miniaturization of physical components has enabled design, development and launch of such small low-cost spacecrafts and to date, more than 60 universities, institutions and research organizations have taken part in CubeSat program since its inception in 1999[1]. Institute of Space Technology (IST) adopted the concept of CubeSat development by initiating the satellite program, ICUBE. ICUBE is the premier student satellite program of any educational institution/university in Pakistan. The first satellite of this program is named ICUBE-1. Successful launch of ICUBE-1 and establishing its communication link with the ground are the primary goals of this mission. The satellite has a passive attitude control system and will carry a CMOS camera for experimental purposes. In this paper, we will discuss in detail the design philosophy of ICUBE-1, followed by the preliminary design and analysis of all its subsystems. The required testing and technical support facilities are discussed before the final conclusions.[1][2]

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1. INTRODUCTION

CubeSat became a de-facto picosatellite standard with an objective to educate and involve students in spacecraft design, development and operational phases. Stanford's Space Systems Development Laboratory (SSDL) and California Polytechnic State University's Multidisciplinary Space Technology Laboratory (MSTL) initiated the CubeSat concept in 1999 [1] when they defined certain specifications for a CubeSat. These small satellites were supposed to be launched as a piggy-back along with the primary payload of a launch vehicle (LV), therefore, certain specifications regarding a common interface between the spacecraft and the launch vehicle were developed to facilitate the launch process of the CubeSats as secondary payloads.

The Poly-Picosatellite Orbital Deployer (P-POD) was developed by CalPoly [2] whose primary objectives were to ensure the safety of launch vehicle as well as its primary payload. The secondary objectives included the proper deployment and safety of the CubeSats. Development of P-POD also reduced the concern levels of the launch providers as they now knew in advance about the secondary payload interface. Since its initial design, P-POD has had several improvements; thanks to the feedbacks provided by its users. P-POD is constructed from high strength, low cost aluminium 7075-T73 and can carry up to three 1U (1-unit) CubeSats, which are deployed by opening a spring loaded door as commanded by the ground station [2]. After deployment from P-POD, the CubeSats are separated in space by the separation springs located between the CubeSat structures [1].

The launch opportunities are generally coordinated by the CubeSat organization and CalPoly [3] along with the recent addition of NASA's CubeSat Launch Initative [4] and ISIS-Innovative Solutions in Space, Netherlands [5], leaving behind only the spacecraft design and development tasks for the universities. Historically, small spacecrafts have low development budget which is further reduced by the evolution of CubeSat standard and developers now can entirely concentrate on the development process leaving the hassle of launch coordination to other organizations.

IST, with the same philosophy, initiated the small low-cost spacecraft development program in 2009. The first satellite of this program, ICUBE-1, is scheduled to be launched by the 3rd quarter of 2011. ICUBE-1 will carry an experimental imaging payload having a small, low resolution CMOS camera, capable of taking continental scale images of Earth. A Telemetry, Tracking and Command (TT&C) ground station has already been developed at IST to fulfil the communication requirements

[1] 978-1-4244-7351-9/11/$26.00 ©2011 IEEE
[2] IEEEAC paper #1758, Version 8.2, Updated January 08, 2011

with ICUBE-1. The development of other required facilities including a clean room, thermal vacuum chamber and vibration test facility are also under way.

The total duration of ICUBE-1 project is estimated to be approximately one and a half years. The project will be facilitated by the use of some Commercial off-the Shelf (COTS) components and modules already flown in space. The subsequent missions of ICUBE program will carry only the indigenously developed modules. The timeline of the ICUBE-1 project is shown in Figure 1.

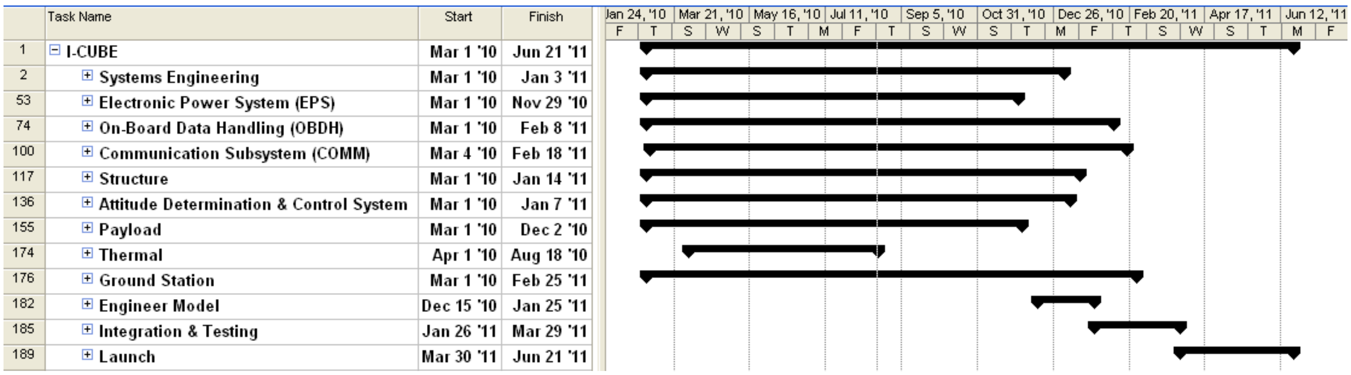

Figure 1 – Estimated timeline of the ICUBE-1 project

2. ICUBE

The ICUBE project is initiated by IST with an objective to provide students the skills and experiences required to build pico and nano satellites. ICUBE follows the learn-by-doing philosophy of CubeSat. The primary mission objective of ICUBE is to design, develop, integrate and launch picosatellite standard CubeSat. The secondary objectives are the communication, in-orbit operation and collection of the payload data. The experience and knowledge acquired during the development and operation of ICUBE-1 would eventually be utilized to develop future CubeSats with more complex subsystems and science missions. The data obtained from several subsystems would be utilized as a baseline to develop better subsystems. In the future, this program will allow the graduates of IST to be involved in all phases of spacecraft development, launch and operation. The baseline design philosophy adopted for ICUBE-1 is to use space-proven commercial components to ensure a certain level of reliability while maintaining the low development cost.

A. Preliminary 1st Order Design

Orbit: Small spacecrafts are generally launched with primary payload and thus their orbital attributes are dependent on the mission requirements of the primary payload. The exact orbit information of the ICUBE-1 is not known, however, it is expected that the satellite would be launched in a low Earth, circular, Sun-Synchronous orbit (SSO). The orbital altitude is expected to be 600-700 km but for the sake of analysis, orbital altitude of 650km is assumed. The SSO is chosen primarily to ensure access to ICUBE-1 from every place on the Earth.

The inclination of ICUBE-1 is approximately 98° according to the chosen parameters. The orbital period of ICUBE-1 is 97.72 minutes with maximum eclipse time of 35.37 minutes. Dawn-dusk and noon-midnight SSO are the two extreme cases from the power generation and thermal point of view. In a dawn-dusk orbit, spacecraft will spend almost all its life in sunlight with little or no eclipses. It is best-case for the power generation but worst-case from the thermal point of view. On the other hand, for noon-midnight orbit, spacecraft will experience maximum eclipse time which is better for the thermal subsystem but not for power generation. Both worst-case situations are used for the thermal and power analysis of ICUBE-1.

The ground track of the ICUBE-1 is obtained by STK simulation as shown in Figure 2. It is clear from the figure that ICUBE-1 is accessible from every place on the Earth. Also, ICUBE-1 is in contact with the IST ground station 4-5 times a day with a total communication window of approximately 54 minutes every day.

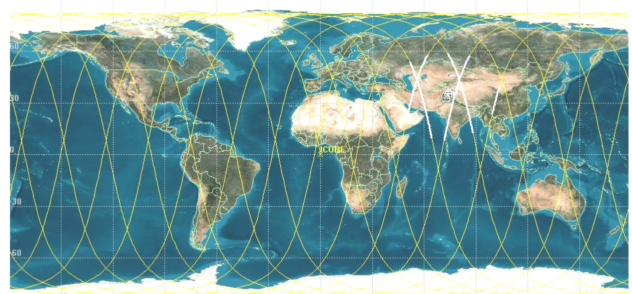

Figure 2 – ICUBE-1 expected ground track

Operational modes: To estimate and identify the power requirements, and define proper procedures and the processing requirements, the functional operations of ICUBE-1 are divided into five modes. These modes are emergency, power saving, normal, payload and transmit mode. These modes can be switched automatically by an on-board computer (OBC) depending on mode specific input and output requirements. The modes can also be switched manually by tele-command as desired by the ground operation. The launch sequence is only a one-time procedure executed immediately after deployment.

The launch sequence and initialization guidelines are provided in the CubeSat specifications [1]. After deployment from P-POD, the deployment switch is released and the batteries are connected to the system bus. A 15-30 minute delay is necessary before the deployment of any structure, such as antenna or boom, to ensure enough separation between the CubeSats sharing the same P-POD. After successful deployment of antennas, ICUBE-1 will enter the power saving mode if the battery charge is under a certain threshold. In power saving mode, all the subsystems of ICUBE-1 will be powered-off except the on-board computer. When the available power reaches the required threshold, ICUBE-1 will be switched to normal mode, while performing the routine housekeeping tasks as well as transmission of a beacon signal at predetermined intervals.

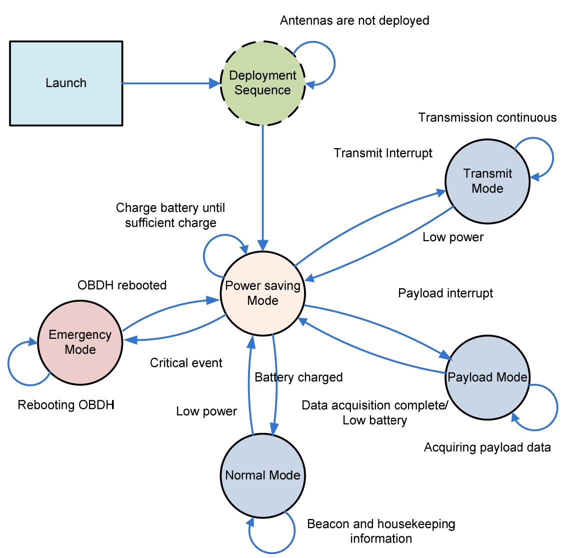

Figure 3 – Operational modes of ICUBE-1

ICUBE-1 will be switched to emergency mode in case of any unwanted event and anomaly detection such as SEU and SEL. In that case, all subsystems of the satellite will be immediately powered off and the on-board computer will be rebooted by a watch dog timer. In the payload mode, ICUBE-1 will perform payload related tasks such as image acquisition, compression and transfer to the storage memory. Normal housekeeping and data collection is also performed during this mode of operation. All the payload data and housekeeping information stored in the on-board memory will be transferred to the ground station. ICUBE-1 will operate in transmitting mode during contact with the ground station. It will also accept commands from the ground station and will act accordingly. The flow diagram of all the operational modes of ICUBE-1 is given in Figure 3.

3. ICUBE-1 SUBSYSTEMS

In order to ease the design as well the development process, ICUBE-1 is divided into several subsystems based on functionality. Each subsystem is being developed independently and the whole system will be integrated after the successful development of each subsystem using common predefined electrical, mechanical and data interfaces. The subsystems are discussed in detail below.

Structure: Structure dimensional requirements are imposed by the CubeSat Design specifications [1] .The 1U CubeSat must be a 10cm cube with a maximum mass of 1.33kg. The 2U and 3U dimensions are also possible while maintaining the two dimensions constant and varying the third dimension. These dimensional requirements were mainly governed by the availability of solar cells in 40mm x 80mm form factor [6]. The bulk material suggested for the main structure is Aluminium 7075 or 6061-T6 or any other material with the same thermal expansion as of P-POD material, 7075-T73. These materials are suggested mainly because of good strength, ease of machining and low cost [1]. The participation of several universities and organizations in the CubeSat project resulted in introducing new companies providing off the shelf components for CubeSat development. Pumpkin Inc. USA is one of those, supplying CubeSat kits including the structure as well as the on-board computer.

Figure 4 – ICUBE-1 1U structure

ICUBE-1 will use the space-proven 1U solid-wall structure from Pumpkin Inc. shown in Figure 4. The structure conforms to all the design requirements of CubeSat. The bulk material used in the structure is aluminium 5052-H32 and the feet are machined from aluminium 6061-T6. The rail surfaces, which are in contact with the P-POD, are hard anodized to provide smooth motion and prevent the satellite from cold welding within the P-POD. The rest of the structure is alodined and acts as faraday's cage to protect ICUBE-1 from external electric fields. A Remove Before Flight (RBF) pin is also provided with the kit to keep the CubeSat inactive during transportation and launch. One deployment switch and two separation springs are present according to the CubeSat Design Specifications. The Pumpkin's CubeSat structure has good flight heritage [7].

Power: Due to the small physical dimensions of CubeSat, the power generation capability always remains limited. With the advancement in solar cell manufacturing technology, it is possible to fabricate more than 30% efficient Ultra Triple Junction Cells (UTJ) which is almost double the efficiency of the conventional Silicon solar cells. Obviously, UTJ cells are more costly than the less efficient cells. ICUBE-1 will use Advanced Triple Junction (ATJ) cells. Five faces of ICUBE-1 have solar panels consisting of two solar cells on each panel capable of delivering approximately 2W of power. Each cell has a dimension of 40mm x 80mm with an efficiency of more than 27.5% @ 25°C in the BOL.

The power board is provided by Clyde-Space shown in Figure 5. It has a good flight heritage [7] and is capable of providing +3.3V and +5V regulated power bus along with the unregulated battery bus. The power supply unit is also compatible with the on-board computer and the other subsystems of ICUBE-1. The power board is more than 90% efficient and has over current and under voltage protection [5]. It has three battery charge regulators (BCR), each capable of handling 3W of power. The telemetry of the power supply unit consists of battery and bus voltages and currents along with the temperature of the solar panels and batteries. The telemetry data is transferred to the on-board computer via I^2C data bus. The power board is also equipped with Maximum Power Point Tracking (MPPT) to keep the operating point of the power subsystem at an optimal level.

Two rechargeable lithium-ion polymer batteries are connected in series with the power board to provide necessary storage capacity during eclipses. Each battery has a capacity of 1500mAh at 3.7V. Lithium polymer batteries are popular for their high storage density and greater life cycle degradation rate. The batteries are charged/ discharged at C/2 rate using the taper charge method i.e. they can provide approximately 5W of continuous power for two hours when fully charged. Furthermore, each battery is provided with a heater which can be turned on and off by sending commands via I^2C bus which keeps the batteries temperature within the operating range for optimum performance.

Figure 5 – Power Board of ICUBE-1

Communication: Communication subsystem is one of the most critical subsystems of ICUBE-1. Without reliable communication, a satellite is of no use. In ICUBE-1, amateur frequency bands would be used for uplink and downlink communication. The use of amateur frequency band is open to amateurs and hobbyists and has relatively limited coordination requirements. Also, a number of ground stations are already using this frequency band which makes it possible for ICUBE-1 to communicate with other ground stations. The exact uplink and downlink frequencies will be finalized after coordination with International Amateur Radio Union (IARU). ICUBE-1 will use VHF range for uplink and UHF range for the downlink. Audio Frequency Shift Keying (AFSK) will be used to send commands to the ICUBE-1 in uplink at a data rate of 1200bps. BPSK with date rate of 1200 bps will be used in the downlink to receive the telemetry and payload data from the satellite. The communication system is also capable of transmitting a CW beacon periodically carrying telemetry data in Morse code format. It is used not only to easily identify the satellite but also to transmit data regarding the basic satellite health.

The transceiver used will have the output power of approximately 300mW. AX25 protocol will be used as a data link protocol for packet communication. Two antennas, one monopole and one dipole will be used for uplink and downlink respectively. The antennas are stowed during launch and will be deployed according to the launch sequence.

On-Board Computer: The on-board computer (OBC) of ICUBE-1 is FM430 shown in Figure 6 will be provided along with the CubeSat kit by Pumpkin Inc. The processing unit of the OBC is an ultra low power 16 bit microcontroller from Texas Instruments, MSP430F1612. This microcontroller has very low power consumption and the whole flight board only consumes a maximum of 2mA current. The microcontroller has 55KB of flash and 5KB of RAM. 12 bit ADC and DAC is supported by this microcontroller. A SD card slot is also available for mass data storage up to 2GB. Three different data communication buses I^2C, SPI and USART are available for data transfer between different subsystems. I^2C will be mainly used for inter-subsystem data transfer i.e. for sending commands to various subsystems and to gather housekeeping information from different sensors. The electrical connections between the different subsystems are made using PC104 form factor bus which reduces the harnesses requirements in limited volume of CubeSat. The flight board FM430 has a good flight heritage and has already been used in several successful CubeSat missions [7].

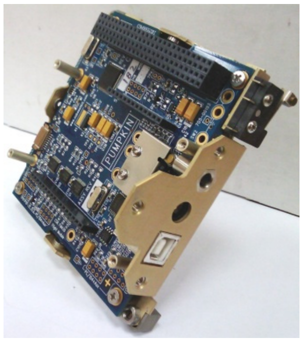

Figure 6 – On Board Computer of ICUBE-1: FM430

Attitude Control Subsystem: ICUBE-1 being the first spacecraft design project of IST will use robust design procedures to increase its reliability. Therefore, a passive attitude control system will be used in the satellite instead of a complex active attitude determination and control system. Passive attitude control systems are popular in low cost small spacecrafts due to design simplification. In relatively large low cost satellites, the gravity gradient passive attitude control system is used due to the possibility of deploying large structures to create the gravity differential. However, in small spacecrafts, passive control is achieved by using a permanent magnet that aligns the spacecraft with the Earth's magnetic field.

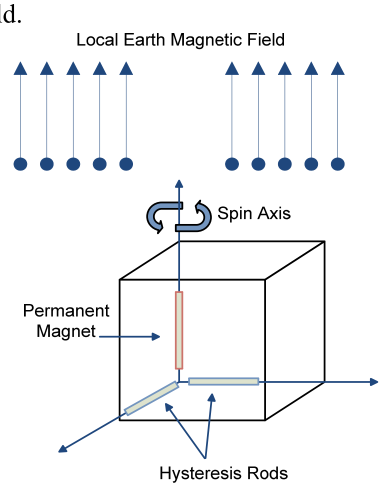

Figure 7 – Passive attitude control system

ICUBE-1 has one-permanent magnet and two hysteresis rods for passive attitude control system. The permanent magnet is attached to one axis of ICUBE-1 and the hysteresis rods are held perpendicular to the permanent magnet as shown in the Figure 7. The axis carrying the permanent magnet will lock ICUBE-1 with the magnetic field of the Earth however the satellite is free to rotate around this axis. Thus the hysteresis rods are placed perpendicular to each other and to the permanent magnet to dampen and oppose these rotations. The limitation of this attitude control system is that the ICUBE-1 will change its orientation as it travels from the South Pole to the North Pole and vice versa according to the Earth magnetic line of forces as shown in Figure 8. Due to this behaviour, it will be possible to take images of only one hemisphere of the earth.

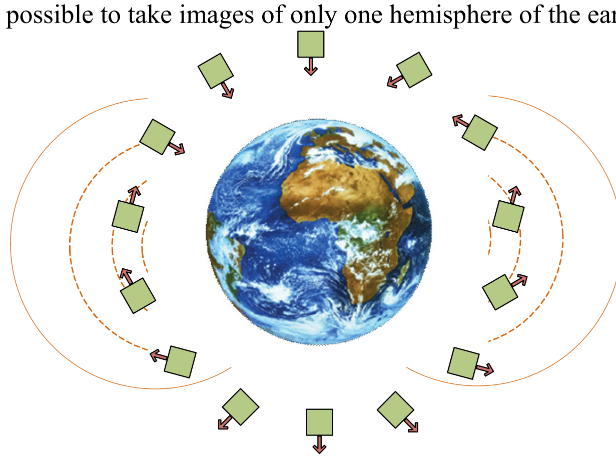

Figure 8 – Passive attitude control system

Payload: As discussed before, the primary mission objective of ICUBE-1 project is to successfully launch and operate the satellite with fully functional telemetry and tele-command links. The secondary mission objective is to take images of the Earth and store them in the on-board memory card for transmission to ground. For that purpose, a low resolution CMOS imaging module C3188A will be used in ICUBE-1. The module is shown in Figure 9. It consists of an Omnivision OV7620 CMOS colour sensor. The resolution of the sensor is 664 x 492 pixels with a pixel size of 7.6µm. The camera uses 1/3" lens with a focal length of 6mm. Due to the harsh environment of the space, special lens may be required for the camera. If we consider an altitude of 650km, each pixel transforms into a ground area of 824m x 824m as shown in Figure 10.

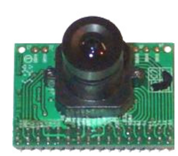

Figure 9 – C3188A camera module

Each raw image will take 980,064 bits of data for storage. However, due to the low data rate downlink and limited communication window, the image will first be compressed using the jpeg compression algorithm. The compression of the image is achieved using a separate microcontroller, other than the on-board computer. The data will later be transferred to the OBDH memory or ground station according to the requirement.

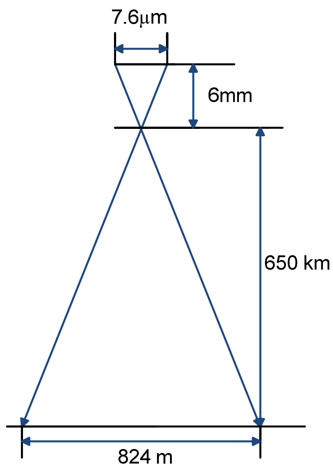

Figure 10 – Ground resolution of OV7620 CMOS sensor

Antenna Deployment Mechanism: ICUBE-1 will use a half-wave dipole antenna for the downlink and quarter-wave monopole for the uplink. The dimension of the dipole antenna is approximately 35cm's and that of the monopole is approximately 50cm's. Due to dimensional constraints of CubeSats, both the antennas will be stowed so that the external dimension will not exceed 6.5mm from the outer surface of the ICUBE-1. The antennas would be released by melting a nylon wire using some heating material. The deployment mechanism is in the design process in consultancy with ISIS-Invoative Soultions in Space, Neitherlands.

4. Systems Engineering Analysis

Systems engineering includes the analysis of ICUBE-1 with the perspective of an overall system as shown in Figure 11. It consists of the environmental analysis, power, link, mass and data budgets. Different analysis and studies performed from the system engineering point of view are presented below.

Environmental Analysis: It is necessary to analyse and understand the hostile space environment in order to mitigate its effects on ICUBE-1. The main concerns for the ICUBE-1 include cumulative radiation effects, single event latch-ups, single event upsets, contamination, space debris, surface charging and micro-meteoroids. It is also expected that ICUBE-1 would travel from South Atlantic Anomaly, a region with high energy trapped protons and electrons. ICUBE-1 will spend its life in a low Earth orbit near the peak of the solar cycle which will be expected to occur in 2011-12 [8]. In short, ICUBE-1 will face the extreme space environmental conditions.
The single event upsets are likely to occur and can be mitigated by the use of software and hardware practices i.e. watch dog timers. Also, for single event latch ups, protection circuitry will be used in each subsystem. It is always desirable to use radiation hardened components in the satellite but due to their limited availability and high cost, radiation tolerant commercial components with proven space history will be used in ICUBE-1. The SEU rate expected in the ICUBE-1 orbit using the SPENVIS tool are mentioned in Table 1.

Table 1. Single Event Upset Rate

Total SEU rates		
	Mission total	
Effect	**(bit^{-1} s^{-1})**	**(bit^{-1} day^{-1})**
Total	9.4657E-06	8.1783E-01

Operating modes: As mentioned earlier, ICUBE-1 has five operational modes. The operating details of each mode along with their power consumption are presented in Table 2.

Table 2. Operational Modes of ICUBE

	Emergency	Power Saving	Normal	Payload	Transmit
OBC	Off	On	On	On	On
Power Board	On	On	On	On	On
Beacon	Off	Off	On	On	Off
Transmitter	Off	Off	Off	Off	On
Payload	Off	Off	Off	On	Off
Power Consumption	**100mW**	**166mW**	**866mW**	**1066mW**	**2166mW**

Power Generation and Consumption: The power for ICUBE-1 will be provided by ATJ solar cells. Five faces of the satellite will be covered with the solar cells and one face dedicated for antenna deployment mechanism and CMOS camera lens assembly. The covering area of each solar panel is 80mm x 80mm. In space, the power production will depend on the effective solar panel surface area exposed to the solar flux and the temperature of the solar panels. The expected power production is thus calculated probabilistically and it is assumed that ICUBE-1 is randomly tumbling in space. The effect of Earth albedo is also ignored in this calculation.

The maximum surface area of ICUBE-1 solar panels will be exposed to the solar flux when an edge between the three surfaces will point towards the sun. It will result in the maximum power production of 4.68W which will reduce to 3.92W at 100°C as the efficiency of the ATJ solar cells varies @ -0.06%/°C. The minimum power generated will be 1.80W and 1.51W @ 100 °C, when only one face of ICUBE-1 is facing towards the sun. Another possibility also exists when only two faces of ICUBE-1 are towards the sun which results in power generation of 2.53W and 2.12W @ 100°C.

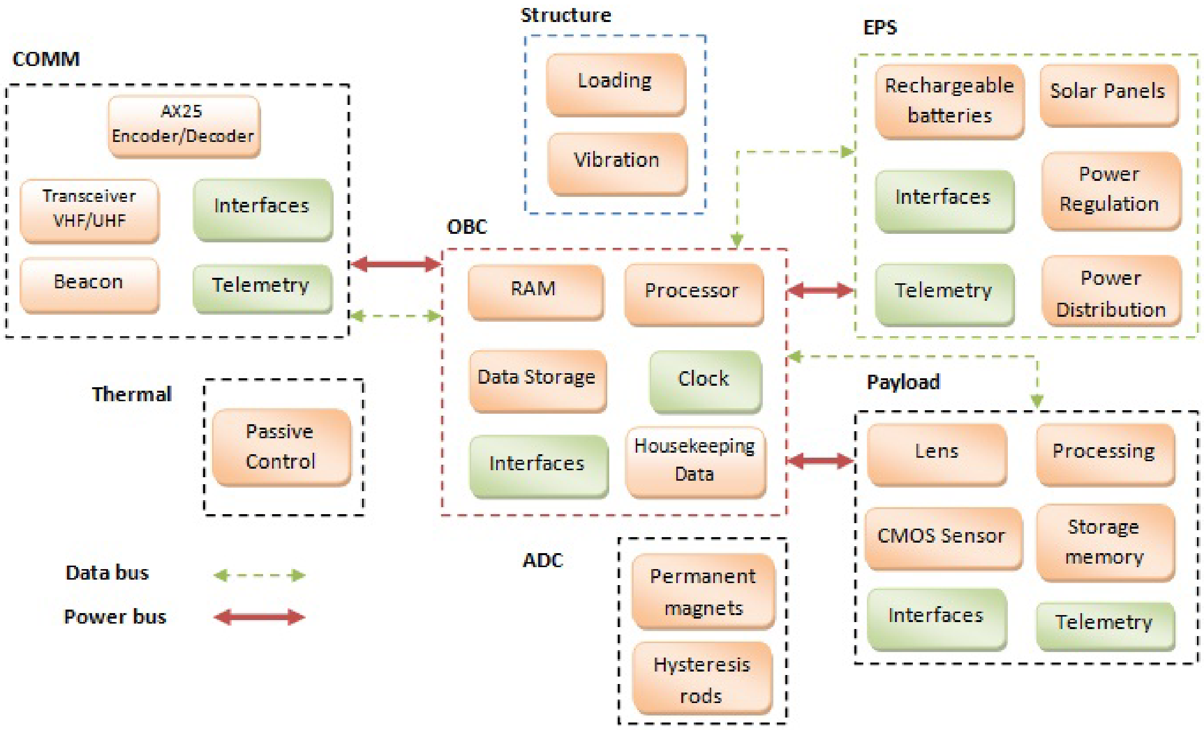

Figure 11 – ICUBE-1 inter-subsystem and intra-subsystem interfaces

Statistically, the average power generated is approximately 3.24W and would reduce to 2.71W at 100°C. Considering the solar panels EOL efficiency to be 22%, the average power generation reduces to 2.59W and 2.06W at 100°. The expected power generation would the ICUBE-1 power requirements. The Table 3 shows the power consumption of each subsystem of ICUBE-1.

Table 3. Power Consumption

Subsystem	Value	Units
OBC	66	mW
PSU	100	mW
Payload	200	mW
Transmitter	2000	mW
Receiver	300	mW
Beacon	700	mW

Mass budget: The total mass of the satellite must be less than 1.33kg as mentioned in CubeSat Design Specifications [1]. From the systems engineering point of view, 50 grams should always be left as a margin. Thus all the subsystems and components should accommodate within the 1280 grams. 10% contingency must be added for each component unless the mass is verified in the laboratory. The mass budget of the ICUBE-1 is given in Table 4.

Uplink & Downlink Budget: The worst-case uplink and downlink communication budget analysis is important to ensure proper and reliable data transfer. The exact orbital altitude of ICUBE-1 is currently unknown and hence for the communication link analysis, the worst-case orbital altitude of 1000km is assumed. It is also assumed that a minimum elevation angle of 10° is necessary to establish the communication link. The worst-case slant range between the ICUBE-1 and ground station becomes 2763km, which is used to calculate the free space loss.

Table I. Mass Budget

Subsystem	Component	Mass (g)	Mass + 10%
OBDH			
	Flight Board	74	81.4
	SD card	2	2.2
COMM			
	Transceiver	85	93.5
	Antenna	100	110
Power			
	PSU	94	103.4
	Solar panel	150	165
Structure			
	Main structure	135	148.5
	Solar panel clips	9	9.9
Payload		150	165
Miscellaneous		100	110
Total		**899**	**988.9**

The uplink budget is given in Table 5 and it shows a margin of 30.08dB. The downlink budget is given in Table 6 and it shows a margin of 9.62dB for a data rate of 9600bps and 18.65dB for a data rate of 1200bps.

Table 5. Uplink Budget

Parameter	Value
Ground Station Transmitter power output	20dBW
Ground Station Line Losses	2.9dB
Ground Station Antenna gain	16.42dBi
Ground station Antenna pointing loss	1.2dB
G/S to S/C Antenna polarization loss	2dB
Path Loss	154.04dB
Atmospheric Loss (min Elevation Angle 10°)	2.1dB
Ionospheric loss	0.8dB
S/C Antenna pointing loss	4.7dB
S/C Antenna Gain	5.19dBi
System Noise Temperature	18.6dBK
S/C Line losses	1dB
Desired Data rate (1200bps)	30.79dBHz
Implementation loss	1dB
E_b/N_o required (AFSK)	21dB
E_b/N_o Achieved	51.08dB
Margin	30.08dB

Thermal Analysis: Thermal subsystem is responsible for keeping the spacecraft subsystems and components within the operating thermal range. Generally, the temperature of a spacecraft can be expected to vary from -200 °C to +100 °C. In ICUBE-1, the thermal subsystem is passive in nature. The exception though is the heater used to keep the batteries above 0°C for optimum performance. A preliminary steady state thermal analysis was performed on the ICUBE-1 to calculate the expected temperatures.

Table 6. Downlink BUDGET

Parameter	Value
S/C Transmitter power output	-5.2dBW
S/C Line Losses	0.4dB
S/C Antenna gain	2.15 dBi
S/C Antenna pointing loss	0.3 dB
S/C to G/S Antenna polarization loss	0.2dB
Path Loss	144.54dB
Atmospheric Loss	2.1dB
Ionospheric loss	0.8dB
G/S Antenna pointing loss	1.2dB
G/S Antenna gain	12.52dBi
Ground Station Line Losses	2.9dB
G/S Effective noise temperature	26.59dbK
Desired Data Rate (9600 bps)	39.82dBHz
E_b/N_o required (BPSK 9600 bps)	9.6dB
E_b/N_o achieved	19.22dB
Margin	9.62dB
Desired Data Rate (1200 bps)	30.79dBHz
E_b/N_o required (BPSK 1200 bps)	9.6dB
E_b/N_o Achieved	28.25
Margin	18.65dB

Thermal analysis tools ESARAD and ESATAN are used and two extreme cases for hot and cold are defined for the analysis purpose. The thermal operating range of different components used in ICUBE-1 is given in Table 7.

Table 7. Operating Temperature Range

Subsystem	Value	Units
OBC	-20 to +85	°C
PSU	-20 to +60	°C
Payload	-10 to +70	°C
Transmitter	-20 to +60	°C
Receiver	-20 to +60	°C
Beacon	-20 to +60	°C
ACS	-50 to +100	°C
Solar Panels	-100 to +100	°C
Batteries	0 to +40	°C

In space, the main source of heat is the direct solar flux whose density is approximately 1367 W/m^2. The Earth reflected solar flux, Albedo, is approximately 30% of the direct solar flux. In addition, there is also the presence of Earth IR emission whose density is approximately 230W/m^2 on ground and can be determined for a satellite in a particular orbit. The amount of the direct solar flux absorbed by the top surface of ICUBE-1 facing towards the sun is simulated in Figure 12.

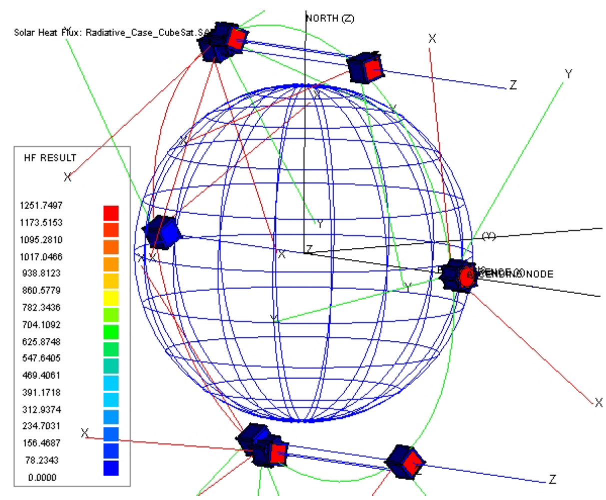

Figure 12 – ICUBE Radiative Analysis

The absorbed flux comes out to be 1251.74 W/m^2 and the absorbed Earth albedo and Earth IR are calculated to be 304.43 W/m^2 and 179.32 W/m^2 respectively by ESARAD. The steady-state maximum temperatures of ICUBE-1 solar panels are calculated theoretically as 69.49°C and the minimum temperature as -16.16°C. These results are verified by the ESATAN software and the results are shown in Figure 13.

Data Budget: The data stored in the on-board computer memory and the SD card of ICUBE-1 will consist of the different sensors output as well as the images taken by the CMOS imaging camera. This data will be eventually transferred to the ground station using AX25 data link layer protocol. This protocol is used for packetized communication along with its error detection capability. ICUBE-1 has a communication window of approximately

54 minutes per day with the IST ground station. The telemetry data budget is presented in Table 8 and the AX25 packet budget is presented in Table 9. The payloads data budget is mentioned in Table 10 which is followed by the overall data budget in Table 11.

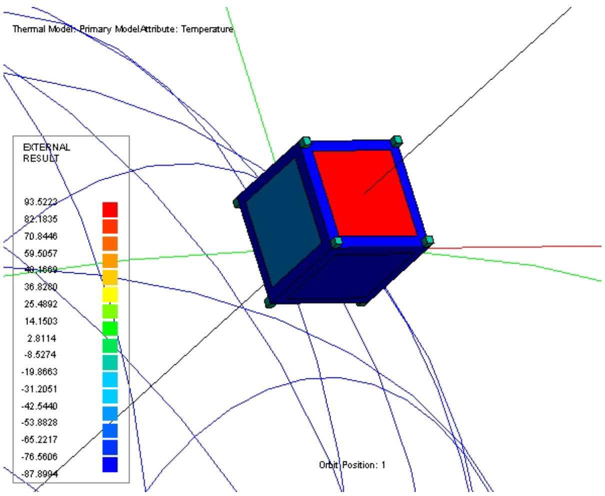

Figure 13 – ICUBE-1 Thermal Analysis

Table 8. Telemetry Packet Data Budget

Variable	bits	Description
Time	32	System time
Panel X_1& X_2 voltage, current & temperature	96	Voltage, current and temperature of x-axis panel
Panel Y1& Y2 voltage, current & temperature	96	Voltage, current and temperature of y-axis panel
Panel Z1& Z2 voltage, current & temperature	96	Voltage, current and temperature of z-axis panel
Battery 1 & 2 voltage	32	Battery voltages
Battery 1 & 2 current	32	Battery currents
Battery 1 & 2 temperature	32	Battery temperatures
Battery 1 & 2 current direction	32	Battery charging or discharging
Transceiver temperature	16	
OBDH temperature	16	
Structure temperature	16	
Payload temperature	16	
Total	512	Bits
	64	Bytes

Table 9. AX25 Packet Budget

Field	bits	Description
Flag	8	Frame Delimiter
Address	112	Source and destination of each frame
Control	8	Type of the frame
PID	8	Network layer information
Info	128	Information (32-2048)
FCS	16	Frame check sequence
Flag	8	Frame Delimiter
Total	288	Bits
	36	Bytes

Table 10. Payload data budget

Field	bits	Bytes
Raw image data	7,840,512 bits	980KB
JPEG Compression 90% Quality	392,025	49KB

Table 11. Overall data budget

Field	1200bps	9600bps
Mean Pass duration	10.5 min	
Mean Link Time / Day	54.7 min	
Maximum Data transferred / day	3,938,400 bits 492 K Bytes	31,507,200 bits 3.93 M Bytes
AX25 Frame overhead	44.44%	
Error rate	10%	
Net Effective Data rate	546 bps	4373 bps
Effective data transferred/day	1,791,972 bits 224 K Bytes	14,352,186 bits 1.79 M Bytes
Raw images transferred /day	1 in 4.37 days	1.82
90% quality pictures transferred /day	4.57	36.53

5. ENGINEERING SUPPORT FACILITIES

To successfully design, develop and integrate ICUBE-1, special engineering and test facilities are necessary. Proper testing procedures are defined to assure the quality of the spacecraft and its components [9]. The qualification test of a spacecraft and its components certifies that all the spacecraft components and systems are functional and survivable during the launch and in the space environment over the course of its lifetime. These tests include vibration, thermal-vacuum and also electromagnetic compatibility test which is sometimes required. Furthermore, development of a ground station to properly communicate with the spacecraft is also of utmost importance. IST is in the process of developing and upgrading its engineering support facilities required for ICUBE project. It is also planned to provide most of the test facilities within IST. However support and test facilities available at other institutions will also be utilized.

Ground Station: IST has recently developed a satellite ground station to support its space development program. The ground station has the capability of receiving data from satellites autonomously. The ground station is also compatible with GENSO and in future, after the release of the GENSO public software, IST will also participate in this educational network of ground stations to achieve global coverage.

The ground station can transmit and receive in VHF and UHF bands with separate crossed Yagi antennas for both horizontal and vertical polarization. A small dish is also mounted for the reception of S-Band signals. The Azimuth and Elevation rotor assembly control the orientation of the antennas through computer tracking software. The satellite earth station transceiver is connected with the antennas via coaxial cable which is capable of generating 100W of power. It is specially designed for satellite operations. Several TNC's are connected with the transceiver to modulate / demodulate and packetizing the digital data. The earth station is capable of automatically tracking the satellites.

Clean Room: Spacecrafts are developed in a clean environment to avoid any captured dust particles and surface contamination especially on the electro-optical components such as solar cells. This development process enhances the reliability of the spacecraft. IST is in the process of developing a class 10,000 clean room. Clean rooms available at other institutions will be utilized until the facilities are available in-house.

Thermal Vacuum Chamber: The thermal requirements of spacecraft are guided by its thermal subsystem design and its orbit of operation. All the components and subsystems must survive extreme temperature conditions to ensure proper working of the spacecraft. To test and qualify the components according to the required thermal environment, the components and the whole spacecraft will be mounted in a thermal-vacuum chamber with controlled thermal and vacuum environment. The spacecraft is exposed to the specified thermal cycle and tested according to the requirement [10].

Outgassing is the slow release of gas that is trapped in the material, under very low pressure conditions such as in vacuum. Outgassing can contaminate optical surfaces such as solar cells and thus it is highly desirable to use the low-outgassing materials in any spacecraft. Outgassing can increase in high temperature. Thermal bake out is thus required to identify the outgassing material and also to remove any trapped gases during the bake out not only at the component level but also at the integration level.

Shake Table: All the subsystems and components of ICUBE-1 must survive the transportation and launch process. Launch vehicle produces extreme vibrations during its ascent and causes acceleration of several g's. The structure of ICUBE-1 must be capable of surviving these extreme shocks and vibrations and must remain intact not only for the success of the mission itself but also to ensure the safety of other payloads and the launch vehicle. The vibrations may range from 20Hz to 2000 Hz [9] depending on the launch vehicle. The spacecraft and the components are exposed to the specified vibration and acceleration using shaker drives along the entire three axis. In a similar way, ICUBE-1 will require the qualification and acceptance vibration test.

Launch: The launch is an integral part of the spacecraft mission. Generally, the small spacecrafts are launched as a piggy-back along with the primary payload. Moreover, the orbital parameters are also imposed by the primary payload and the other payloads have to modify their missions according to these constraints. Currently, due to more participation of world-wide institutions in the CubeSat program, CubeSat organisation has started coordinating launches for CubeSats. Some third parties are also coordinating launch process for CubeSats. This reduces the overall launch and procedural cost, leaving only the task of spacecraft development to the mission designers. IST is also in contact with some of the launch coordinators and providers to secure a reliable and low cost launch of ICUBE-1.

6. Conclusions

In this paper, the initial subsystem analysis and preliminary design of ICUBE-1 has been discussed. The educational value expected to be achieved during this project would become a baseline for designing future space missions in the institute. The design of ICUBE-1 focuses on the use of already space-proven components and excessive testing of the COTS components. The preliminary thermal analysis and power production at the system level have been accomplished. The orbital attitude and the expected environmental analysis have also been completed. A preliminary engineering model of ICUBE-1 is being designed using these simulation parameters and analyses results and it would ultimately be followed by the development and integration of the flight model. The development of the flight model is expected to be completed by mid 2011. The in-house development facilities will also be identified and developed for the future space missions.

Acknowledgment

We would like to thank the IST management especially the Vice Chancellor for initiating the ICUBE program and supporting the development of first student satellite.

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BIOGRAPHY

Rehan Mahmood *received his Bachelors degree in electrical engineering from University of Engineering & Technology, Taxila, Pakistan and the M.Sc. degree in satellite communication engineering from University of Surrey, UK in 2002 and 2006, respectively. From September 2002 until August 2005 he worked in Institute of Space Technology, Islamabad where he was involved in the R&D activities along with the teaching of basic communication systems courses. After M.Sc. he again joined IST as a lecturer teaching spacecraft related courses. Beside the teaching activities, he is also the project engineer of the ICUBE-1 project.*

Khurram Khurshid *received his Bachelor's degree in software engineering from National University of Sciences & Technology, Rawalpindi in 2002and completed his masters and PhD in Image Processing from Paris Descartes University in 2006 and 2009 respectively. Since then he has been actively participating in projects related to Satellite Imagery and Satellite Payload design and development. He is currently working as an assistant professor in IST. He is also the project manager of ICUBE-1 project.*

Qamar-ul-Islam *is an expert in the area of satellite system design and wireless communication. He has more than twenty years of international experience in research, development and teaching. Presently (2005 to date), he is Head of Department (HoD), Communication Systems Engineering, Institute of Space Technology (IST), Islamabad. In addition to managing the undergraduate/ graduate programs and research work, he is also: Chief Editor of a peer reviewed journal of space technology, Project Director: ICUBE-1 project, Member IST Board of Governors (August 2007 to July 2010). He completed BSc Electrical Eng from UET, Lahore in 1982 and MS/ PhD from University of Surrey (1986 and 1991 respectively) in the field of Satellite Communication Engineering. He did research work at BT Research Labs. He served as Technical Advisor ARABSAT for a period of five years (1996-2000) on satellite projects. He joined Bell Canada Wireless in January 2001. He led projects on Wireless, Instant Messaging, WAP, IMG, Net Alerts; participated in the design of Location Based Services (LBS); and 3G mobile, CDMA2000 System. He also completed executive management studies from Massachusetts Institute of Technology (MIT), Sloan School of Management, Boston, USA (1999) and Schulich School of Business, York University, Toronto, Canada (2001). His research interests are in wireless, satellite systems, antennas and mobile communication.*