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Communications Regulatory Authority
State of Qatar

هيئة تنظيم الاتصالات
دولة قطر

Name

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Presentation Title

CubeSat at Qatar University: Amateur Satellites as Educational and Capacity Building Platform

Abstract

In this presentation, we will discuss standardized pico-satellites called CubeSat and their potential as capacity building and educational tools. The presentation will discuss the key features of CubeSat design and implementation. The presentation will also discuss the initiative of the CubeSat multidisciplinary project at Qatar University and its potential future progress.

Bio data

Tamer Khattab received the B.Sc. and M.Sc. degrees in electronics and communications engineering from Cairo University, Giza, Egypt, in 1993 and 1999, respectively and the Ph.D. degree in electrical and computer engineering from The University of British Columbia (UBC), Vancouver, BC, Canada, in 2007. From 1994 to 1999, he was with IBM wtc, Giza, Egypt, as a development team lead. From 2000 to 2003, he was with Nokia (formerly Alcatel Canada Inc.), Burnaby, BC, Canada, as a senior member of the technical staff. He joined Qatar University (QU) in 2007, where he is currently a Professor of Electrical Engineering and the Director of the Center for Excellence in Teaching and Learning (CETL). He is also a senior member of the technical staff with Qatar Mobility Innovation Center (QMIC). His research interests cover satellite and aerial communications, information theory, and RF sensing techniques. He has recently started exploring the emerging area of quantum communications. He served as an editor for the IEEE Communication Letters, IEEE Transactions on Communications and IEEE Open Journal of the Communications Society. He is currently leading the Intelligent Information Processing Lab (IIPL) at Qatar University and the CubeSat project.

QUBSat: Qatar University cuBeSat project

A students' mega project

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Outline

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1. Introduction
   - Motivation and historical background
   - A briefing on CubeSat
2. CubeSat System
   - The orbital deployer (P-POD)
   - The CubeSat standards
3. The CubeSat System Design
   - Design
   - Subsystems Details

Motivation and History of CubeSat

- Space technology is traditionally moving towards larger more complex and high cost systems
- Technology was only available to few large scale organizations that can afford the required resources
- In the last decade interest was in small scale low cost and complexity space systems with high power efficiency
- In 1999 CubeSat was originally conceived at Stanford University's Space Systems Development Laboratory joint with California Polytechnic State University (Cal Poly)
- The launching and standardization process is maintained and handled by Cal Poly

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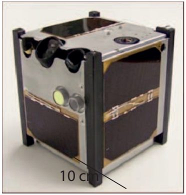
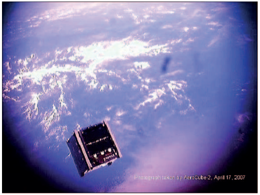
What is CubeSat?

In a nutshell

CubeSat

A standardized, low cost, low complexity and very small satellite (called pico-satellite) that can be built using commercial off–the–shelf (COTS) components, can be adopted for different missions and allows for batch (multiple) low cost launching into orbit.





What is CubeSat?

Properties

- **Standardized** in terms of its mechanical properties
- **Low cost** due to its standardization, mission choice and orbital choice
- **Low complexity** due to its orbital and mission choices
- **Small** size and low weight by design and standardization choice

What is CubeSat?

Benefits

- **Utilizes COTS** because of its standardization and high interest
- **Flexible mission** by nature of satellite systems design and limited scope of standardization as well as availability of COTS
- **Low cost launching** due to availability of batch launching stemming from standardization and small size

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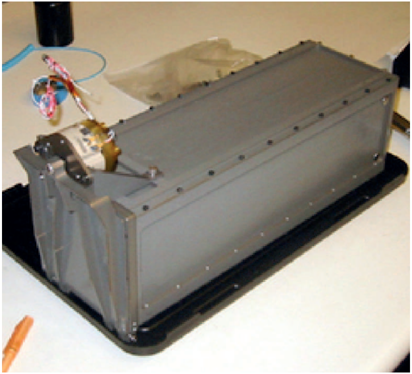
The poly-picosatellite orbital deployer (P-POD)

Characteristics

- Standardized deployer maintained by Cal Poly
- Driven by the need for consistency in design and launching to enable batch launching



The poly-picosatellite orbital deployer (P-POD)

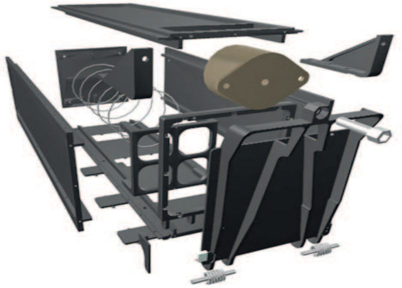
Objectives

- Protect the primary payload
- Protect the launch vehicle
- Protect the CubeSats
- Safely group multiple CubeSats for launch
- Eject CubeSats for safe deployment
- Increase access to space for CubeSats
- Provide a standard interface to launch vehicles

The poly-picosatellite orbital deployer (P-POD)

Specifications

- Aluminum box of tubular design
- Has an ejection spring for non-explosive release.
- Can accommodate up to three 1U CubeSats.

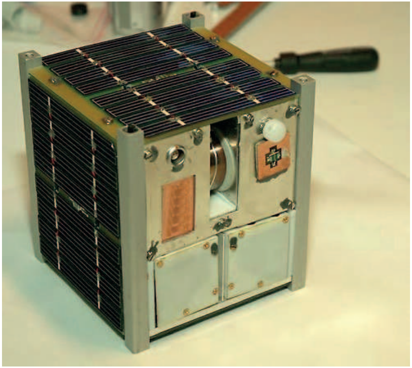


Outline

The CubeSat standards

General specifications

- 10cm cube (called 1U)
- Can be 2U up to 12U maximum
- Maximum weight per 1U is 1.33kg

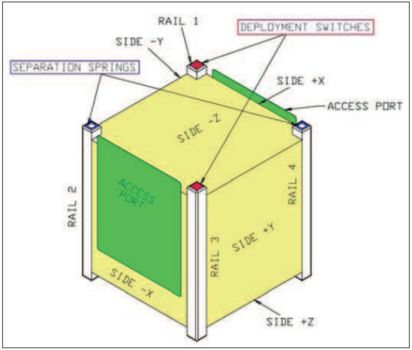


The CubeSat standards

Categorizations

The requirements can be categorized into

- General
- Mechanical
- Electrical
- Operational

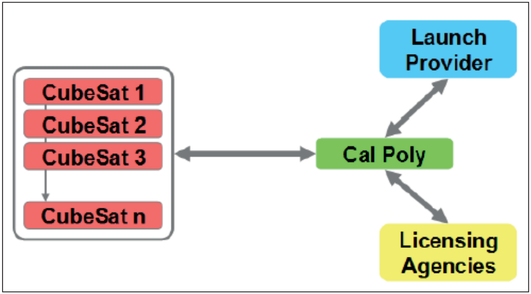


The CubeSat standards

The role of Cal Poly

Traditionally Cal Poly is the organization responsible for:

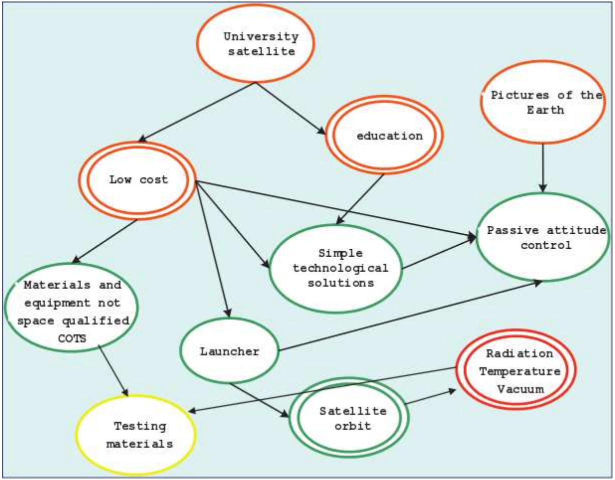
- Maintaining the CubeSat standards
- Developing, testing and flying the P-POD
- Coordinating CubeSat developers and launch providers.
- Coordinating launches for CubeSat



Outline

System Design

Requirements



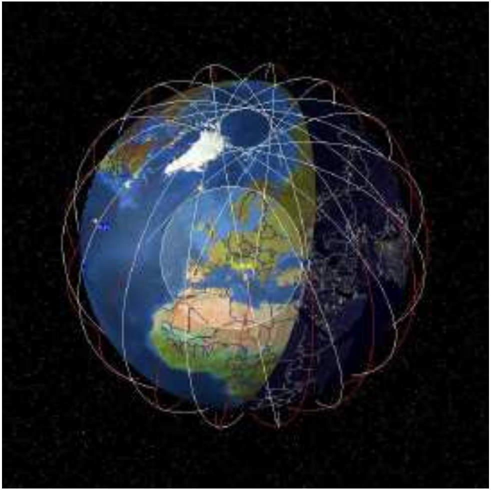
Environmental Constraints

Satellites flying in Low Earth Orbit (LEO) have the following environmental constraints:

- Operational temperature (-50ºC to +150ºC)
- Vacuum ➔ outgassing and thermal dissipation
- Radiations ➔ Single Event Latch-up (SEL)
- Radiations ➔ Single Event Up-set (SEU)
- Distance (telecommunication)

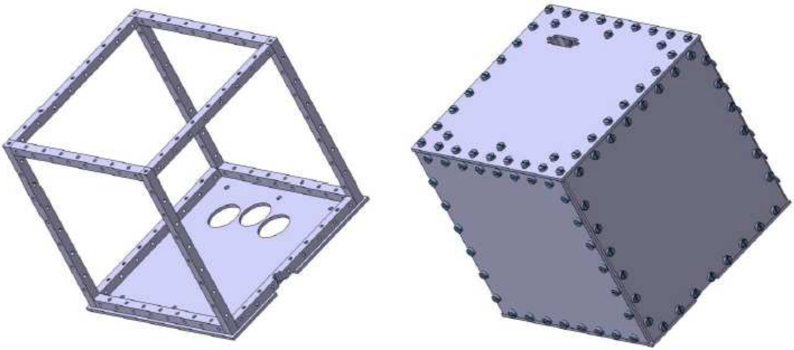
The CubeSat Subsystems

Orbit



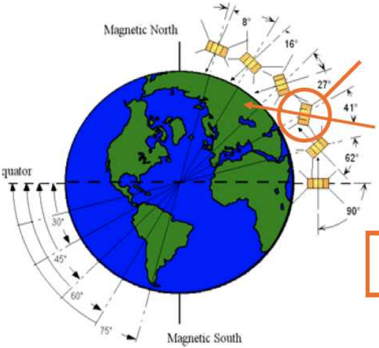
Outline

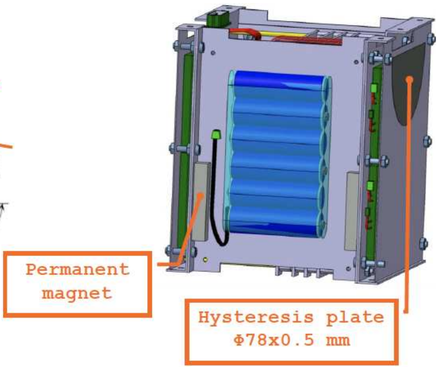
Structure



System Design

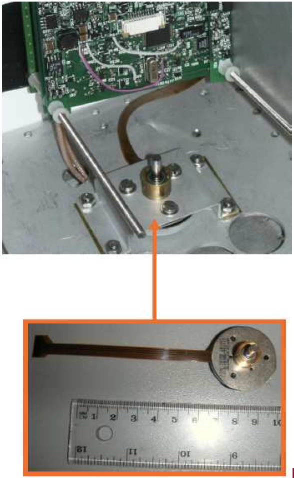
Attitude Control - Passive





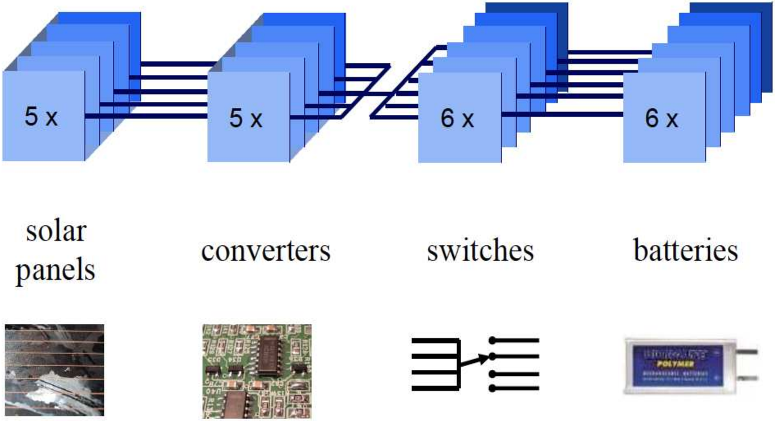
Attitude Control - Active

- Magnets control **PICPOT** attitude only about two axes
- To achieve three axes control, a reaction wheel is mounted on the x-axis
- It is driven by a MAXON brushless motor
- Attitude control is not autonomous and requires ground intervention (autonomous control is not necessary to take pictures of Europe)
- The main interest lies in testing the reaction wheel itself



Maxon EC 32 flat motor data	Value
Power rating [W]	6
Nominal voltage [V]	9
No load speed [rpm]	8600
Stall torque [mNm]	20
No load current [mA]	110
Max. continuous current at 5000 rpm [A]	1.03
Rotor inertia [g*cm^2]	13.9
Weight [g]	32
Ambient temperature range [°C]	-40/+100

Power System - Components



System Design

Power System - Budgeting

Power sink	Duty cycle (%)	Power when active (mW)	Avg. power (mW)
Payload cameras: active only when triggering a photo; max 2s every orbit	0.03	1,200	3.6
Payload image compressor: active only after triggering a photo; max 30s every orbit, or 150s every 5 orbits	0.5	1,320	6.6
Payload communication to on-board data handling: active only while transmitting a photograph after triggering a photo; max 50s every orbit, or 250s every 5 orbits	0.8	1,320	10.5
Standard telemetry transmission, 435MHz: active max. 2s every minute	3.33	5,600	185
Extended telemetry and payload transmission, 435MHz; additional power when inside the ground station horizon: 53s each min when inside the horizon (avg 5 min every orbit; 5 orbits every twelve)	1.84	5,600	103
Standard telemetry transmission, 2.4GHz: active max. 2s every minute	3.33	3,000	100
Extended telemetry and payload transmission, 2.4GHz; additional power when inside the ground station horizon: 53s each min when inside the horizon (avg 5 min every orbit; 5 orbits every twelve)	1.84	3,000	55
TOTAL			495
Margins & derating (+50%)			247
TOTAL			742

Power System - Sources ...

- Five solar panels, which cover as many faces of the satellite.
- Each solar panel is about 4”x4”, that is $100mm^2$.
- By taking into account that:
  - only one or at most two panels are exposed at a time at sunlight;
  - when one panel, it is perpendicular to sunlight;
  - when two panels, they are 45º from sunlight to panel;
  - only one or two panels are exposed at Earth albedo (30% of sunlight)
- Total equivalent panel surface is about **$150mm^2$**.
- Sun power density at LEO is about 1,200 W/m^2
- Average persistence of satellite in the day is about 60%
- Total average power from sun is about **11.2W**.
- Average efficiency of solar panels, over the expected temperature range (0÷60ºC) is 23%, which we derate to 20%.
- Average electrical power from solar panels is **2.24W** (averaged over a number of orbits; worst case for temperature and derating)

Power System - Sources

- Energy is stored on a collection of six packs of rechargeable batteries
- Two groups of three packs (each pack supplies half satellite, for redundancy)
- Each pack contains either two Li-P element or six NiCd element
- 7.2V typical for each pack. Capacity is 1.5 Ah (10.8Wh) for Li-P and 0.9Ah (6.5Wh) for NiCd. Max. available energy is then 56.2Wh.
- Each pack in turn is charged from the five solar panels via an hysterethic switching supply.
- Worst case efficiency of charger is 70% = **1.56W** to recharge batteries.
- Worst case efficiency of battery is 75% (over temperature, after 60 cycles = three months of expected and properly derated for radiation)
- Expected recharge time is 12.2h (Li-P) and 7.3h (NiCd).
- Total recharge time for the whole satellite is therefore **63.4h**.
- It results an average power available for all electronic systems of **1.17W**
- Total storage time of about **2.5 days** (all batteries fully charged; avg. power consumption of 820mW).

Onboard Computer - Requirements

On-board data handling processors are required to:

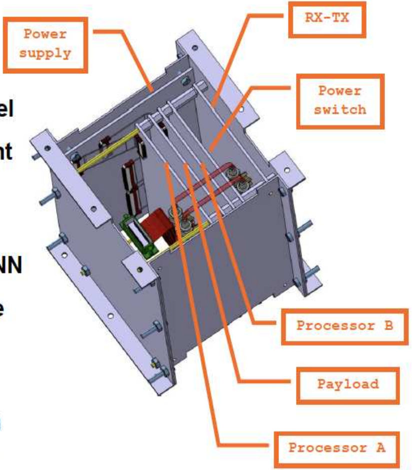
- Communicate with ground station (via RF channel)
- Acquire telemetry data every minute (50 sensors)
- Store telemetry statistics for one orbit (100 min)
- Control battery charging strategy

Onboard Computer - Example

Five processors on board:

1. Housekeeping A: Chipconn 1010
   - 437.478 MHz commun. channel
2. Housekeeping B: Texas Instrument MSP430
   - 2.440 GHz commun. channel
3. Payload: Analog Devices BlackFINN
   - image compression & storage
4. Timing generators: PIC16F706 + MSP430, replicating functions

Processor A and B replicate the main housekeeping satellite functions.



Communications Systems - Link Budgeting Downlink

Downlink

Inputs		
Constant name	Symbol	
Bandwidth	B (Hz)	2.00E+05
Boltzmann Constant	k	1.38E-23
Transmission Band	f	9.26E+08
Wavelength		3.24E-01
Transmitter Antenna Diame	Dt (inches)	6
Transmitter Antenna Diame	Dt (m)	0.1524
Transmit Antenna Efficiency		0.7
Receiver Antenna Diamete	Dr (ft.)	10
Receiver Antenna Diamete	Dr (m)	3.048
Receiver Antenna Efficiency		0.7
Satellite Altitude	Alt (m)	520000
Earth station antenna heig	Ant. Height (m)	53.9496
Max. Distance	r (m)	2652288.16780986
Room Temperature	To (K)	290
Sky Temperature	Tsky (K)	50
Power in	Pin (dBm)	0
Noise in	Ni (W)	8.00E-16

Legend	
Titles	
Givens/Constants	
User Inputs	
Calculations	
Chosen Modulation Scheme	64QAM

Outputs	Symbol	Value
Effective Isotropic Radiated Po	EIRP (dBm)	35.52
Power Out	Pout (dBm)	0.00766566990611
Noise Out	Nout (dBm)	-2.63E+01
Signal-to-Noise Ratio	SNR (dB)	2.63E+01

Modulation Scheme	64QAM	256QAM
Data Rate (bps)	1.20E+06	1.60E+06
Eb/No (Factor)	7.10E+01	5.32E+01
Eb/No (dB)	1.85E+01	1.73E+01
L	8	16
x	4.50360103440252	2.23851544245288
BER (x/bit)	0.00000203697412	0.00681973632047

Component Name	Link Element	Symbol	Noise figure (dE	Gain (dB)	Signal Power (dBn	Noise Power (dBn	SNR (dB)
Transmitter							
					0	-1.21E+02	1.21E+02
Custom	**Pre-processor**	Lpre	3	-3	-3	-1.21E+02	1.18E+02
LT5560	**Up-converter**	Gup	9.3	2.4	-0.6	-1.09E+02	1.09E+02
CBPU5013537	**HPA**	GHPA	8	35	34.4	-7.29E+01	1.07E+02
AD897-942D201	**Duplexer**	Ldp	1	-1	33.4	-7.39E+01	1.07E+02
SS402	**Cable**	Lft	0.03	-0.03	33.37	-7.40E+01	1.07E+02
Channel							
	Transmit Antenna Gai	Gt		2.15	35.52	-7.18E+01	1.07E+02
	Free Space Path Loss	Lfs		-1.60E+02	-1.25E+02	-2.32E+02	1.07E+02
	Atmospheric Loss	Latm		0	-1.25E+02	-2.32E+02	1.07E+02
	Receiver Antenna Gai	Gr		2.79E+01	-9.69E+01	-2.04E+02	1.07E+02
Receiver							
	Receiver input noise	Nin(Ntrans+Nsky)			-9.69E+01	-1.29E+02	3.17E+01
SS402	**Cable**	Lfr	0.03	-0.03	-96.892334330093	-1.28E+02	3.16E+01
AD897-942D201	**Duplexer**	Ldp	1	-1	-97.892334330093	-1.26E+02	2.77E+01
HD30161	**Low Noise amplifer ga**	GLNA	0.5	38	-59.892334330093	-8.63E+01	2.64E+01
LT5560	**Downconverter**	Gdown	10.1	2.6	-57.292334330093	-8.36E+01	2.63E+01
SS402	**Cable**	Lct	4	-4	-61.292334330093	-8.76E+01	2.63E+01
Custom	**Attenuator**	Lat	13.7	-13.7	-74.992334330093	-1.01E+02	2.63E+01
PSA4-5043+	**IF Amplifier**	GIF	0.7	25	-49.992334330093	-7.63E+01	2.63E+01
PSA4-5043+	**IF Amplifier**	GIF	0.7	25	-24.992334330093	-5.13E+01	2.63E+01
PSA4-5043+	**IF Amplifier**	GIF	0.7	25	0.00766566990611	-2.63E+01	2.63E+01

Link Element	Noise Figure (Facto	Gain (Factor)	Noise Figure (Factor)	Noise Power (W)
Transmitter				
Input Noise				8.00E-16
Pre-processor	1.99526231496888	0.501187233627	1.99526231496888	8.00E-16
Up-converter	8.51138038202377	1.737800828749	16.9824365246174	1.18E-14
HPA	6.30957344480193	3162.277660168	2.31E+01	5.09E-11
Duplexer	1.25892541179417	0.794328234724	2.31E+01	4.04E-11
Cable	1.0069316688518	0.993116048420	2.31E+01	4.01E-11
Channel				
Transmit Antenna Gain		1.640589773199		6.58E-11
Free Space Path Loss		1.06E+16		6.22E-27
Atmospheric Loss		1		6.22E-27
Receiver Antenna Gain		6.12E+02		3.80E-24
Ntrans+Nsky				1.38E-16
Receiver				
Cable	1.0069316688518	0.993116048420	1.0069316688518	1.43E-16
Duplexer	1.25892541179417	0.794328234724	1.26765186585785	2.78E-16
Low Noise amplifer ga	1.12201845430196	6309.573444801	1.42232878712282	2.37E-12
Downconverter	10.2329299228075	1.819700858609	1.42418376843754	4.33E-12
Cable	2.51188643150958	0.398107170553	1.42435069258602	1.72E-12
Attenuator	23.4422881531992	0.042657951880	1.43057465747898	7.42E-14
IF Amplifier	1.17489755493953	316.2277660168	1.43171171841133	2.35E-11

System Design

Communications Systems - Link Budgeting Uplink

Uplink

Inputs		
Constant name	Symbol	
Bandwidth	B (Hz)	1.00E+04
Boltzmann Constant	k	1.38E-23
Transmission Band	f	9.10E+08
Wavelength		3.30E-01
Transmitter Antenna Diame	Dt (ft.)	10
Transmitter Antenna Diame	Dt (m)	3.048
Transmit Antenna Efficiency		0.7
Receiver Antenna Diamete	Dr (inches)	6
Receiver Antenna Diamete	Dr (m)	0.1524
Receiver Antenna Efficiency		0.7
Max Satellite Altitude	r (m)	2652288.16780986
Room Temperature	To (K)	290
Sky Temperature	Tsky (K)	290
Power In	Pin (dBm)	0
Noise In	Ni (W)	4.00E-17

Legend	
Titles	
Givens/Constants	
User Inputs	
Calculations	
Chosen Modulation Scheme	BPSK

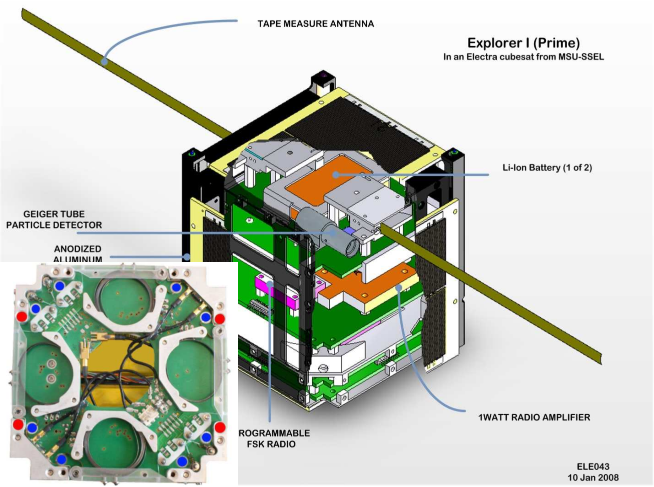
Outputs	Symbol	Value
Effective Isotropic Radiated Po	EIRP (dBm)	5.01E+01
Power Out	Pout (dBm)	0.00766566990613
Noise Out	Nout (dBm)	-2.44E+01
Signal-to-Noise Ratio	SNR (dB)	2.44E+01

Modulation Scheme	BPSK	QPSK
Data Rate (bps)	1.00E+04	2.00E+04
Eb/No (Factor)	2.74E+02	1.37E+02
Eb/No (dB)	2.44E+01	2.14E+01
x	23.402845362901	16.5483106551675
BER (x/bit)	0.00000000000000	0.00000000000000

Component Name	Link Element	Symbol	Noise figure [dB]	Gain [dB]	Signal Power (dBm)	Noise Power (dBm)	SNR (dB)
Transmitter							
					0	-1.34E+02	1.34E+02
Custom	**Pre-processor**	Lpre	3	-3	-3	-1.34E+02	1.31E+02
LT5560	**Up-converter**	Gup	9.3	2.4	-0.6	-1.22E+02	1.22E+02
CBPU5013035	**HPA**	GHPA	8	30	29.4	-9.09E+01	1.20E+02
SS402	**Cable**	Lfd	6	-6	23.4	-9.69E+01	1.20E+02
AD897-942D201	**Duplexer**	Ldp	1	-1	22.4	-9.79E+01	1.20E+02
SS402	**Cable**	Lft	0.03	-0.03	22.37	-9.79E+01	1.20E+02
Channel							
	Transmit Antenna Gai	Gt		2.77E+01	5.01E+01	-7.03E+01	1.20E+02
	Free Space Path Loss	Lfs		-1.60E+02	-1.10E+02	-2.30E+02	1.20E+02
	Atmospheric Loss	Latm		0	-110.012334330094	-2.30E+02	1.20E+02
	Receiver Antenna Gai	Gr		2.15	-107.862334330094	-2.28E+02	1.20E+02
Receiver							
	Receiver input noise	Nin(Ntrans+Nsky)			-107.862334330094	-1.34E+02	2.61E+01
SS402	**Cable**	Lfr	0.03	-0.03	-107.892334330094	-1.34E+02	2.61E+01
AD897-942D201	**Duplexer**	Ldp	1	-1	-108.892334330094	-1.34E+02	2.51E+01
SKY67105-306LF	**Low Noise Amplifer**	GLNA	0.7	36	-72.8923343300939	-9.73E+01	2.44E+01
LT5560	**Downconverter**	Gdown	10.1	2.6	-70.2923343300939	-9.47E+01	2.44E+01
Custom	**Attenuator**	Lat	4.7	-4.7	-74.9923343300939	-9.94E+01	2.44E+01
PSA4-5043+	**IF Amplifier**	GIF	0.7	25	-49.9923343300939	-7.44E+01	2.44E+01
PSA4-5043+	**IF Amplifier**	GIF	0.7	25	-24.9923343300939	-4.94E+01	2.44E+01
PSA4-5043+	**IF Amplifier**	GIF	0.7	25	0.00766566990613	-2.44E+01	2.44E+01

Link Element	Noise Figure, Fact	Gain, Factor	Cumulative Noise Figure, Facto	Noise Power (W)
Transmitter				
Input Noise				4.00E-17
Pre-processor	1.99526231496888	0.501187233627	1.99526231496888	4.00E-17
Up-converter	8.51138038202377	1.737800828749	16.9824365246174	5.92E-16
HPA	6.30957344480193	1000	2.31E+01	8.04E-13
Cable	3.98107170553497	0.251188643150	2.31E+01	2.02E-13
Duplexer	1.25892541179417	0.794328234724	2.31E+01	1.61E-13
Cable	1.0069316688518	0.993116048420	2.31E+01	1.59E-13
Channel				
Transmit Antenna Gain		5.91E+02		9.42E-11
Free Space Path Loss		1.02E+16		9.21E-27
Atmospheric Loss		1		9.21E-27
Receiver Antenna Gain		1.640589773199		1.51E-26
Ntrans+Nsky+Nant				4.00E-17
Receiver				
Cable	1.0069316688518	0.993116048420	1.0069316688518	4.00E-17
Duplexer	1.25892541179417	0.794328234724	1.26765186585785	4.00E-17
Low Noise amplifer ga	1.17489755493953	3981.071705534	1.48936107771092	1.87E-13
Downconverter	10.2329299228075	1.819700858609	1.49230102496876	3.41E-13
Attenuator	2.95120922666639	0.338844156139	1.49264245666917	1.16E-13
IF Amplifier	1.17489755493953	316.2277660168	1.49273277662949	3.66E-11
IF Amplifier	1.17489755493953	316.2277660168	1.49273306224628	1.16E-08
IF Amplifier	1.17489755493953	316.2277660168	1.49273306314948	3.66E-06

Communications Systems - Antenna



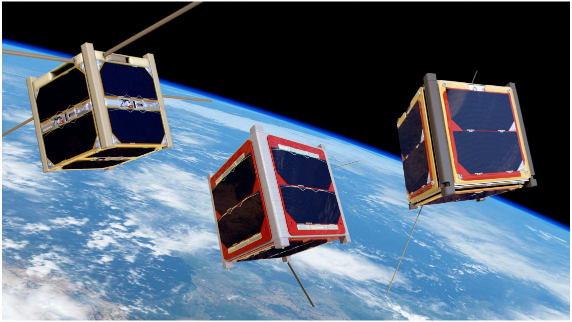
Communications Systems - Transceiver

Top view

Bottom view

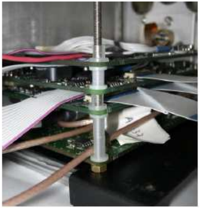
Communications Systems - Frequencies

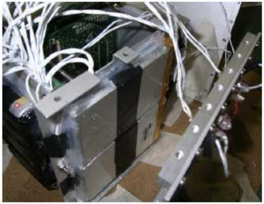
	Option 1	Option 2	Option 3	Option 4
Frequency Band (MHz)	144-146	420-450	1260-1270	2400-2450



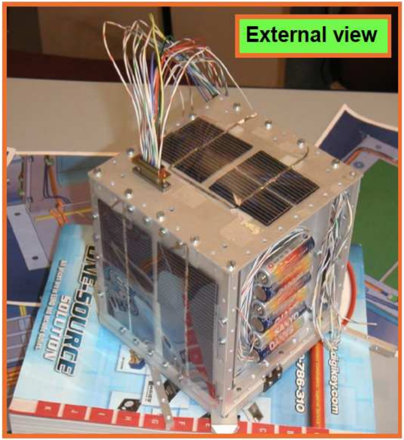
System Design

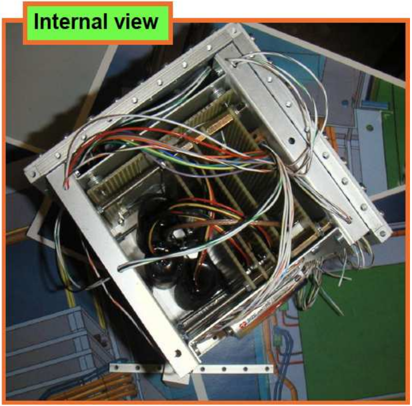
Wiring and Shielding





Let’s hope we reach there





Some QU folks are working on it

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QU CubeSat ground station

QU CubeSat clean room

Summary

- Affordable for universities.
- Multidisciplinary.
- Teamwork, system design and project planning.
- Started as student project and now has research funding.

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