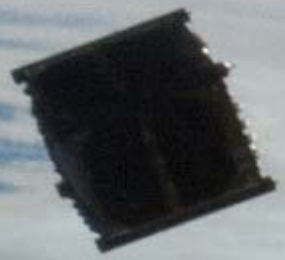
AIAA OC Rocketry

AIAA OC Section – NAR #718

Engaging High School Students in a CubeSat Project



ASAT 2014 May 2, 2015

Jann and Bob Koepke

Photo from NASA

What is a CubeSat?

- Miniaturized Satellite for space research
- Volume of 1 liter (10cm cube)
- Mass of 1.33kg or less (1U)
- Can be multiples of that size (e.g. 2U, 3U)
- Usually uses off-the-shelf components

Photos from ISIS (Innovative Solutions in Space) and ESA.INT

Why CubeSats?

CubeSats provide a focused project for students to experience many aspects of engineering

- Electronics – building and making things work together
- Programming
- Communications – telemetry, images, voice, link budgets
- Power challenges – batteries and solar panels, power budgets
- Structure
- Weight budgets
- Sensors
- Testing
- Improvisation

Photo from Parabolicarc.com

Challenges

- Cost – challenge to keep costs low
- Time – High School Students starting the project may be in college at completion
- Realistic – even if the CubeSat never orbits, it can still get close to space

Photo from ITProPortal.com

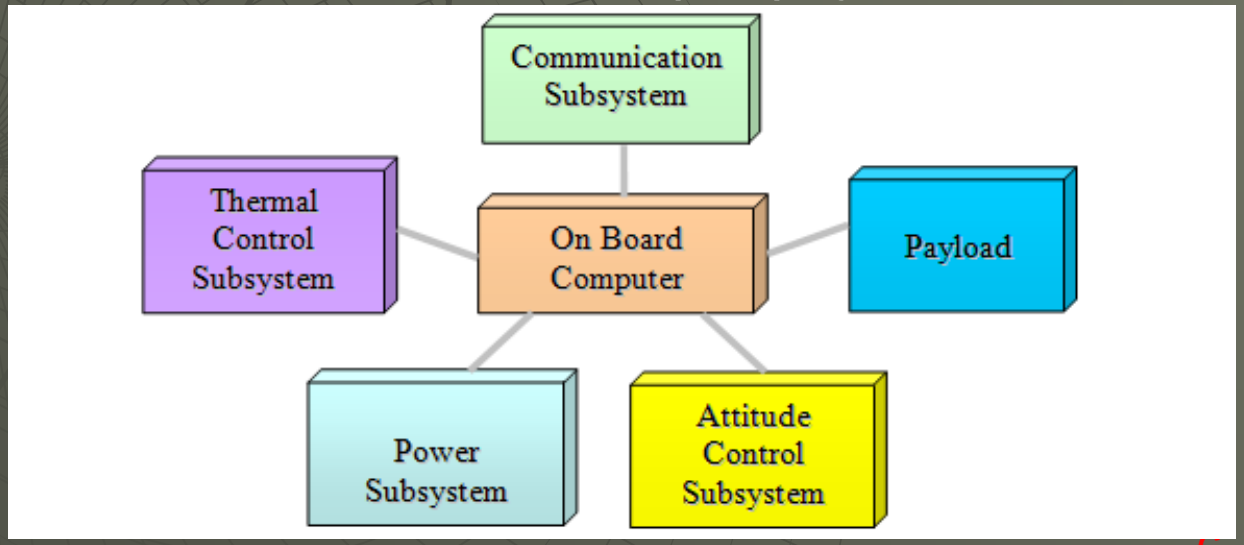
The Program

Goal is to keep students challenged and enthusiastic regardless of when the launch to orbit might be

- Preparation
  - Build and fly the S4 payload (Small Satellites for Secondary Students)
  - Build and fly a CanSat
- CubeSats
  - Research CubeSats, specifications, and regulations
  - Design and build an appropriate ground station
  - System design, build, and ground test a CubeSat
  - Launch that CubeSat on a solid fuel rocket to 1-2 miles
  - Launch that CubeSat to 100,000 ft. on a High Altitude Balloon
  - Group project: Build and launch a CubeSat

Where to start?

- Research
  - What CubeSats are already in orbit?
  - What experiments did they carry?
  - How do they transmit the data to the ground station
  - What is inside?
- Build a ground station to listen to existing satellites
- Extend the ground station to talk through existing satellites
- Start with the satellite foundation – a simple payload can come later
  - Computer
  - Power
  - Communications
  - Attitude control
  - Thermal control



Block Diagram of Masat-1

What's Inside?

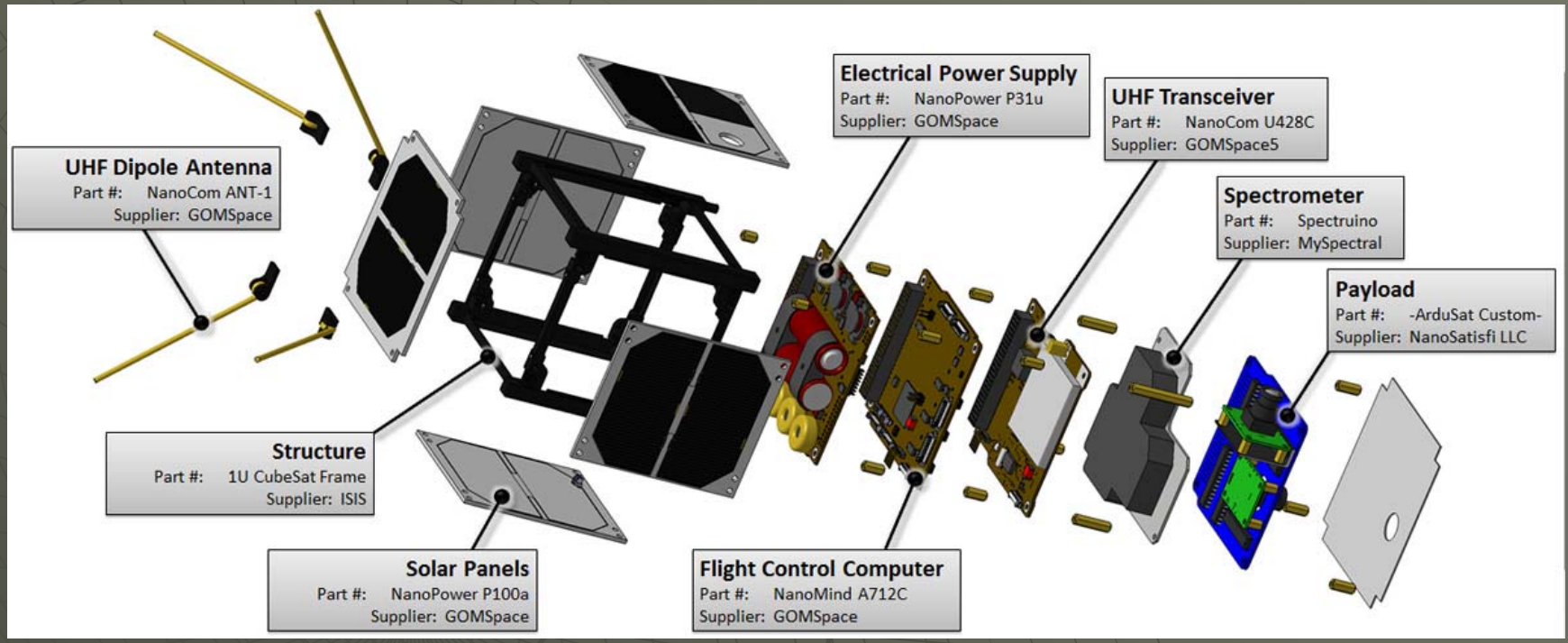


Image from DigiKey

No Shortage of CubeSats

Version 9; Page 1 of 2. This chart shows the 256 total CubeSats deployed in orbit so far, for a total of 499 Units. March 10, 2015.
Bryan Klofas. bklofas@gmail.com. Green are University CubeSats; Red are Commercial or Private; Blue are US Government.

Launch	Satellite	Object	Size	Radio	Downlink	Satellite Service	Power	TNC	Protocol	Data Rate/Modulation	Downloaded	Lifetime	Antenna	Status	Updated
NLS-1/Innovator 30 June 2003	AAU CubeSat	27846	1U	Wood & Douglas SX450	437.475 MHz	amateur	500 mW	MX909	AX.25, Mobitex	9600 baud GMSK	1 kB	3 months	dipole	Dead	April 2013
	DTUsat-1	27842	1U	RFMD RF2905	437.475 MHz	amateur	400 mW		AX.25	2400 baud FSK	0	0 days	canted turnstile	DOA	April 2013
	CanX-1	27847	1U	Melexis	437.880 MHz	amateur	500 mW		Custom	1200 baud MSK	0	0 days	crossed dipoles	DOA	April 2013
	Cute-1 (CO-55)	27844	1U	Alinco DJ-C4 (data) Maki Denki (beacon)	437.470 MHz 436.8475 MHz	amateur amateur	350 mW 100 mW	MX614 PIC16LC73A	AX.25 CW	1200 baud AFSK 50 WPM	>10 MB[2] N/A	118+ months	monopole monopole	Alive	April 2013
	QuakeSat-1	27865	3U	Tekk KS-960	436.675 MHz	amateur	2 W	BrayPac BP-96A	AX.25[3]	9600 baud FSK	425 MB	7 months	turnstile	Dead	April 2013
	XI-IV (CO-57)	27848	1U	Nishi RF Lab (data) Nishi RF Lab (beacon)	437.490 MHz 436.8475 MHz	amateur amateur	1 W 80 mW	PIC16C622 PIC16C716	AX.25 CW	1200 baud AFSK 50 WPM	>11 MB[2] N/A	118+ months	dipole dipole	Alive	April 2013
SSE11 Express 27 Oct 2005	XI-V (CO-58)	28895	1U	Nishi RF Lab (data) Nishi RF Lab (beacon)	437.345 MHz 437.465 MHz	amateur amateur	1 W 80 mW	PIC16C622 PIC16C716	AX.25 CW	1200 baud AFSK 50 WPM	N/A	90+ months	dipole dipole	Alive	April 2013
	ICube-2	28897[4]	1U		437.505 MHz	amateur			AX.25	1200 baud AFSK	0	0 days	monopole	DOA	April 2013
	UWE-1	28892	1U	PR430	437.505 MHz	amateur	1 W	HSS/2674F5	AX.25	1200/9600 baud AFSK		3 weeks	end-fed dipole	Dead	April 2013
M-V-8 22 Feb 2006	Cute-1.7+APD (CO-56)	28914	2U	Alinco DJ-C5 Telemetry (beacon)	437.505 MHz 437.385 MHz	amateur amateur	300 mW 100 mW	CMX589A HSS/2328[5]	AX.25/SRLL CW	1200 AFSK/9600 GMSK 50 WPM	<1 MB N/A	2.5 months	dipole dipole	Deorbited	April 2013
Minotaur-1 11 Dec 2006	GeneSat-1	29655	3U+	Microhard MHX-2400 Stensat (beacon)[7]	2.4 GHz 437.067 MHz	experimental amateur	1 W 500 mW	Integrated[6] PIC12C617	Proprietary AX.25	1200 baud AFSK	500 kB N/A	3 months	patch monopole	Deorbited	April 2013
Dnepr-2 17 Apr 2007	CSTB1	31122	1U	Yaesu VX-2R	100.0375 MHz	experimental	300 mW	PIC	Proprietary	1200 baud AFSK	6.77 MB	18 months	dipole	Dead	April 2013
	AeroCube-2	31133	1U	FreeWave FGRM	915 MHz	experimental	2 W	Integrated[6]	Proprietary	38.4 kbaud	500 kB	1 week	patch	Dead	April 2013
	CP4	31132	1U	TI CC1000/RF2117	437.325 MHz	amateur	1 W	PIC18LF6720	AX.25	1200 baud FSK	483 kB	2 months	dipole	Dead	April 2013
	Libertad-1	31128	1U	Stensat	437.405 MHz	amateur	400 mW		AX.25	200 baud AFSK	0[8]	1 month	monopole	Dead	April 2013
	CAPE1	31130	1U	TI CC1020	435.245 MHz	amateur	1 W	PIC16LF652	AX.25	9600 baud FSK	0[9]	4 months	dipole	Dead	April 2013
	CP3	31129	1U	TI CC1000/RF2117	436.845 MHz	experimental	1 W	PIC18LF6720	AX.25	1200 baud FSK	2.0 MB[2]	191 months	dipole	Dead	April 2013
	MAST[10]	31126	3U	Microhard MHX 2400	2.4 GHz	experimental	1 W	Telgrated[3]	Proprietary	15 kbps	>2 MB	0.75 months	monopole	Dead	April 2013
NLS-4/PSLV-C9 28 Apr 2008	Delfi-C3 (DO-64)	32789	3U	Custom (transponder) Custom (beacon)	145.9-435.55 MHz 145.870 MHz	amateur amateur	200 mW 400 mW	N/A PIC18LF4680	Linear AX.25	30 kHz wide 1200 baud BPSK	N/A 60 MB[11]	60+ months	turnstile turnstile	Alive	April 2013
	Seeds-2 (CO-66)	32791	1U	Musashino Electric (data) Musashino Electric (beacon)	437.485 MHz 437.485 MHz	amateur amateur	450 mW 90 mW		AX.25 CW	1200 baud AFSK	500 kB[2] N/A	60+ months	monopole monopole	Alive	April 2013
	CanX-2	32790	3U	Custom S-Band	2.2 GHz	space research	500 mW	Integrated	NSP	16-256kbps BPSK	250 MB	60+ months	patch	Active	April 2013
	AAUSAT-II	32788	1U	Holger Eckhardt (DF2FQ)	437.425 MHz	amateur	610 mW	PIC18LF6680	AX.25	1200 baud MSK	8 MB[22]	60+ months	dipole	Alive	April 2013
	Compass-1	32787	1U	Holger Eckhardt (data) BC340 (beacon)	437.405 MHz 437.275 MHz	amateur amateur	300 mW 200 mW	C8051F120, FX614 PIC12F629	AX.25 CW	1200 baud AFSK/MSK 15 WPM	<1 MB[2] N/A	60+ months	dipole dipole	Alive	April 2013
Minotaur-1 19 May 2009	AeroCube-3	35005	1U	FreeWave FGRM	915 MHz	experimental	2 W	Integrated	Proprietary	77 kbaud GFSK	52 MB	7 months	patch	Deorbited	April 2013
	CP6	35003	1U	CC1000/RF2117	437.305 MHz	amateur	1 W	PIC18LF6720	AX.25	1200 baud FSK		4 months	dipole	Deorbited	April 2013
	HawkSat-1	35004	1U	Microhard MHX-425	437.345 MHz	amateur	1 W	Integrated	Proprietary		0 kB	0 days	monopole	DOA	April 2013
	PharmaSat	35002	3U+	Microhard MHX-2400 Stensat (beacon)[7]	2.4 GHz 437.465 MHz	experimental amateur	1 W 500 mW	Integrated Integrated	Proprietary AX.25	10 kbps 1200 baud AFSK	650 kB N/A	10 days 1 month	patch monopole	Deorbited	April 2013
ISTLaunch 01/ PSLV-C14 23 Sep 2009	BEESAT-1	35033	1U	STE DK-77B	436.000 MHz	amateur[23]	500 mW	CMX909B	Mobitex	4800/9600 baud GMSK		43+ months	monopole	Alive	April 2013
	UWE-2	35934	1U	Custom	437.385 MHz	amateur			AX.25	1200 baud AFSK		1 week	dipole	Dead	April 2013
	ITUpSAT-1	35935	1U	Microhard MHX-425 BeeLine/CC1050	437.325 MHz 437.325 MHz	amateur amateur	1 W 350 mW	Integrated	Proprietary CW	19200 baud	0 kB[8] N/A	43+ months	dipole monopole	Alive	April 2013
	SwissCube	35932	1U	Butler oscillator/RF5110G RF25:6 (beacon)	437.505 MHz 437.505 MHz	amateur amateur	1 W 100 mW	MSP430F1611 Integrated	AX.25 CW	1200 baud FSK 10 WPM	6 MB N/A	43+ months	monopole monopole	Active	April 2013
H-IIA F17 20 May 2010	Hayato	36573	1U	Custom	13.275 GHz	Earth exploration	100 mW	Integrated		10 kbps/1 Mbps BPSK	0 kB	18 days	patch	Deorbited	April 2013
	Waseda-SAT2	36574	1U	TXE436-301A TXE430-301A (beacon)	437.485 MHz 437.485 MHz	amateur amateur	150 mW 100 mW	HS/3052F5 HS/3052F5	AX.25 CW	9600 baud FSK	0 kB N/A	0 days	monopole dipole	DOA Deorbited	April 2013
	Negai-Star	36575	1U	Data Beacon Radio	437.305 MHz 437.305 MHz	amateur amateur	150 mW 100 mW		AX.25 CW	1200 baud FSK 50 WPM	N/A	1 month	dipole dipole	Deorbited	April 2013
NLS-6/ PSLV-C15 12 July 2010	Ths-1	36799	1U	Alinco DJ-C6 CC1010 (beacon)	437.305 MHz 437.305 MHz	amateur amateur	500 mW 400 mW	MSP430F169 MSP430F169	AX.25 CW	1200 baud AFSK 45 170 WPM	N/A	33+ months	monopole monopole	Active	April 2013
	StudSat	36796	1U	CC1020 MAX1472 (beacon)	437.505 MHz 437.860 MHz	amateur amateur	500 mW 10 mW	UC3A0C2[2] UC3A0512[2]	Custom AX.25 CW	1200 baud FSK 22 WPM	6 kB[8] N/A	5 days	monopole monopole	Dead	April 2013
SLP-S28 19 Nov 2010	RAX-1	37223	3U	Lithium-1	437.505 MHz	amateur	750 mW	Integrated	AX.25	9600 baud GMSK	4.8 MB	2 months	turnstile	Dead	April 2013
	O/OREOS	37224	3U+	Microhard MHX-2400 Stensat (beacon)[7]	2.4 GHz 437.305 MHz	experimental amateur	1 W 500 mW	Integrated Integrated	Proprietary AX.25	Variable 1200 baud AFSK	8 MB N/A	29+ months	patch monopole	Alive	April 2013
	NanoSail-D2	37361	3U+	Microhard MHX-2400 Stensat (beacon)[7]	2.4 GHz 437.370 MHz	experimental amateur	1 W 500 mW	Integrated Integrated	Proprietary AX.25	Variable 1200 baud AFSK	N/A	5 days[24]	patch monopole	Deorbited	April 2013
Falcon 9/02 8 Dec 2010	Perseus (4)	37251+	1.5U			government						1 month	dipole	Deorbited	April 2013
	QbX (2)	37249+	3U	TTC	450 MHz	government	1 W			9600 band GMSK		1 month	quadrifilar helix	Deorbited	April 2013
	SMDC-ONE	37246	3U	Pericle	UHF	government						1 month	turnstile	Deorbited	April 2013
	Mayflower	37252	3U	Microhard MHX 425 Stensat (beacon)[7]	437.000 MHz 437.600 MHz	unlicensed unlicensed	1 W 1 W	Integrated Integrated	Proprietary AX.25	Variable 1200 baud AFSK	0 kB[8] N/A	2 days	dipole	Deorbited	April 2013
PSLV-C18 12 Oct 2011	Jugnu	37839	3U	CC1070/RF5110G MAX1472 (beacon)	437.505 MHz 437.505 MHz	amateur amateur	1 W 10 mW		AX.25 CW	2400 baud FSK 20 WPM	N/A	18+ months	monopole monopole	Alive	April 2013
Soyuz-U/ PPF 28 Oct 2011	AubieSat-1	37854	1U	Melexis TH7201	437.475 MHz	amateur	800 mW	ATmega128[15]	CW	20 WPM	0 kB	22+ months	dipole	Alive	April 2013
	DICE (2)	37851+	1.5U	L3 Cadet	465 MHz	meteorological	1 W	Integrated	Proprietary	2.6 Mbps QQPSK	8.1 GB	20 months	dipole	Dead	Aug 2013
	IIRIE	37855	1U	CC1000	437.505 MHz	amateur	850 mW		AX.25	1200 baud FSK	[11]	22+ months	monopole	Active	Aug 2013

From chart from Bryan Klofas of Cal Poly SLO showing 256 CubeSats deployed into orbit as of March 10, 2015 – but determining which ones are active is a challenge

CubeSat Survey – Communications

- Power: 30mW – 2W
- Frequencies: Ham Radio (2m – 144 MHz to 146 MHz and 70cm – 435 MHz to 438 MHz)
- Antennas: Dipole, monopole
- Modulation: FSK, AFSK, BPSK
- Protocol: AX.25, CW
- Data rates: 1200 – 9600 BAUD

Image from phpweb.tu-Dresden.de

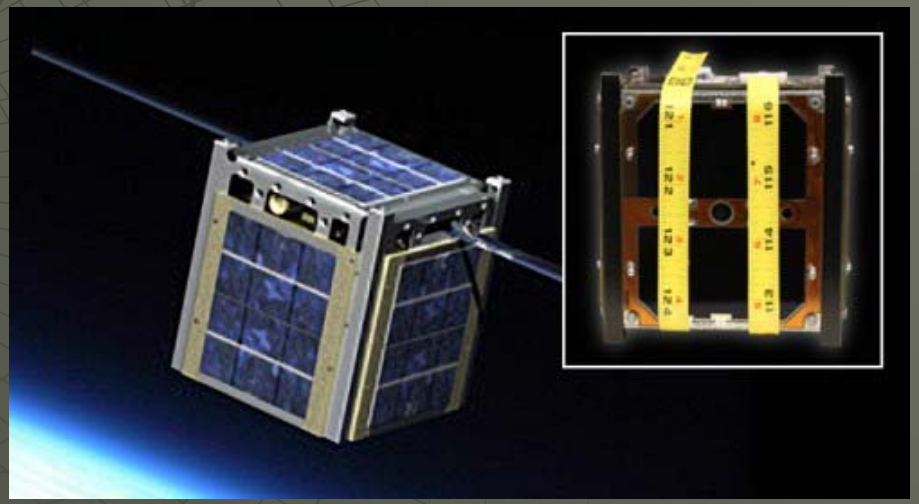


Image from itproportal.com

Sources

Several companies provide CubeSat Parts & Kits

- Tyvak (Tyvak, Terran Orbital)
  - Intrepid – comprehensive 1U solution $30,000
- Pumpkin Inc. (Cubesatkit.com, CubeSatShop.com, Clyde Space)
  - Kit (structure, motherboard, processor board, dev board, misc.) $7500
  - Mechanical Structure (1U) $1500
  - Motherboard $1200
  - Processor $650
  - Software $5,500
  - Power $745
  - Solar Panel $2500
- Interorbital
  - TubeSat Kit with launch (processor board, battery pack, solar cells, more) $8,000
  - CubeSat Kit with launch (processor board, battery pack, solar cells, more) $12,000
- Open Source (LibreCube)
  - Complete solution, plans and software are free but you make everything

LibreCube

An Open Source CubeSat Initiative

Open source is hardware and software developed and shared under a minimally restrictive license

"LibreCube is a non-profit initiative to promote open source CubeSat education": http://cubesat.de/librecube

"Everything for a generic CubeSat Mission

- PCB Design (Schematic, Layout, Gerbers) for
  - Main Computer CPU Board
  - Power Board (batteries and charging from solar panels)
  - Communications Board (UHF data)
- Basic firmware (in "C")
- Test scripts and procedures
- Documentation

Initial builds will for development – first runs not considered flight hardware

Image from LibreCube

LibreCube – Processor

OBC – On board Computer
CDHS – Command and Data Handling System
($80 for parts + PCB)

- Two 8051 microprocessors provide 100 MIPS of processing
- 16MB of FLASH memory
- Operates on 3.3V
- Processors can run fully redundant or separately
- Connectors for two deployment switches
- Uses modified PC-104 electrical bus
- I2C and UART interface for peripheral devices
- JTAG interface for development and programming

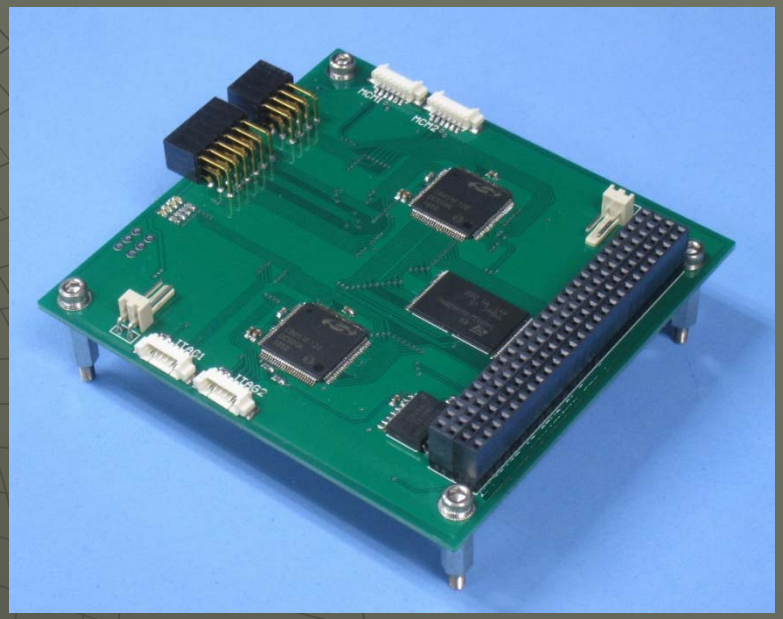


Image from LibreCube

LibreCube – Power

EPS – Electrical Power System
$170 parts + PCB + batteries + solar panels

- Provides and manages power for the entire CubeSat
- Handles charging from six Solar Panels
- Provides raw battery voltage, 3.3V and 5.0V for the system
- Provides state measurement to the system

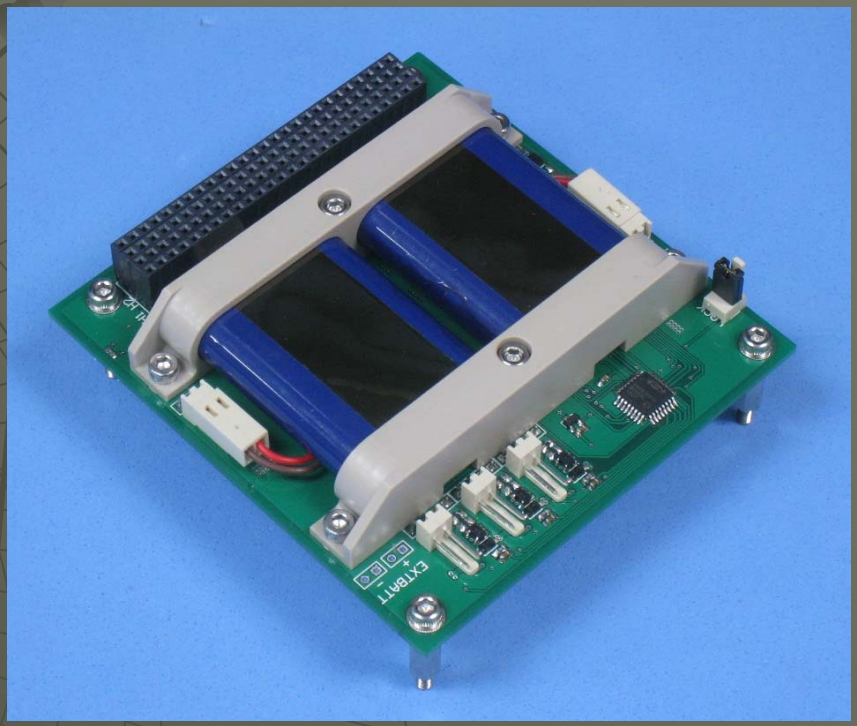


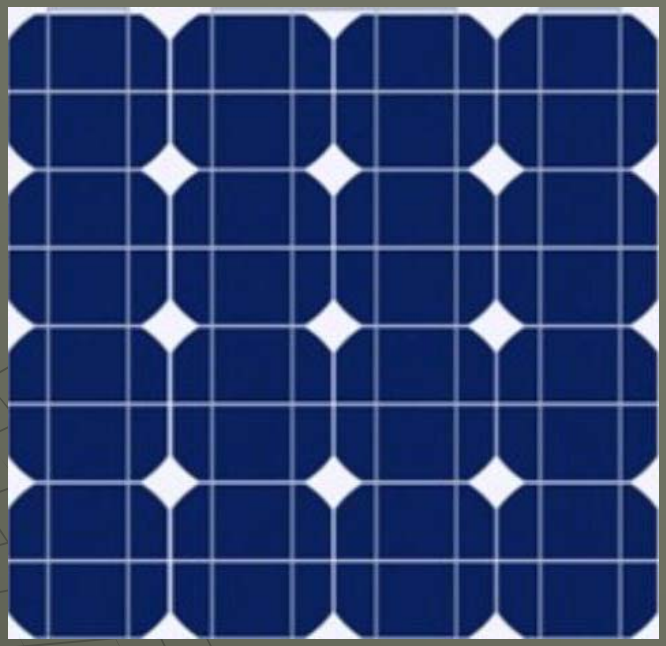
Image from LibreCube

Power Budget

- System power usually comes from batteries
- The batteries need to be charged – usually from Solar cells

The challenge

- How much battery can you afford to carry with the weight limit?
- How much time does the CubeSat spend in sunlight?
- How much of the solar panel array is exposed to the sun and at what angle?
- Need to balance the ability to charge against the power needed by the system



Battery image from OnlyBatteries

LibreCube – Communications

COM - Communications
$110 in parts + PCB

- Half duplex communications system for UHF (435 MHz)
- Up to 1W of output power
- Provides beacon for Morse code message
- Provides ECSS/CCSDS compliant telemetry frames

ECSS is European Cooperation for Space Standardization

CCSDS is Consultative Committee for Space Data Systems

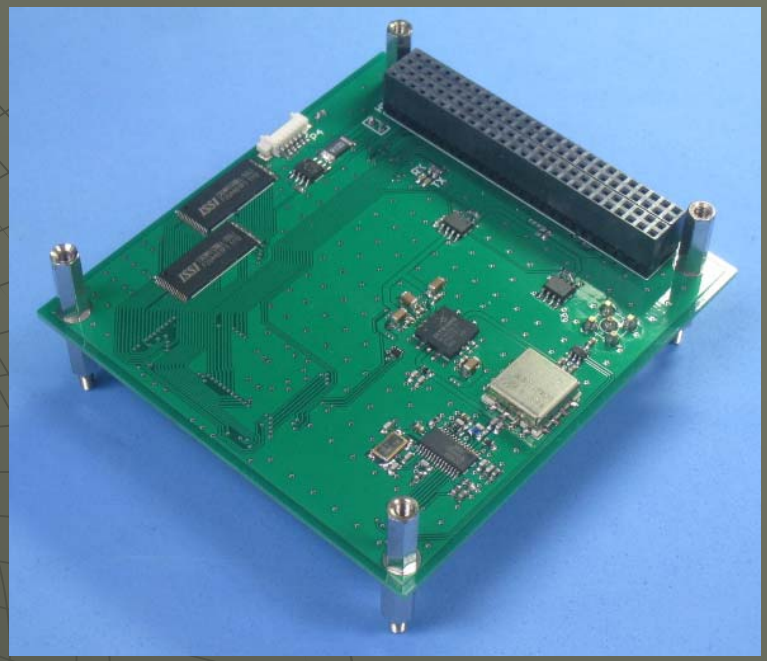
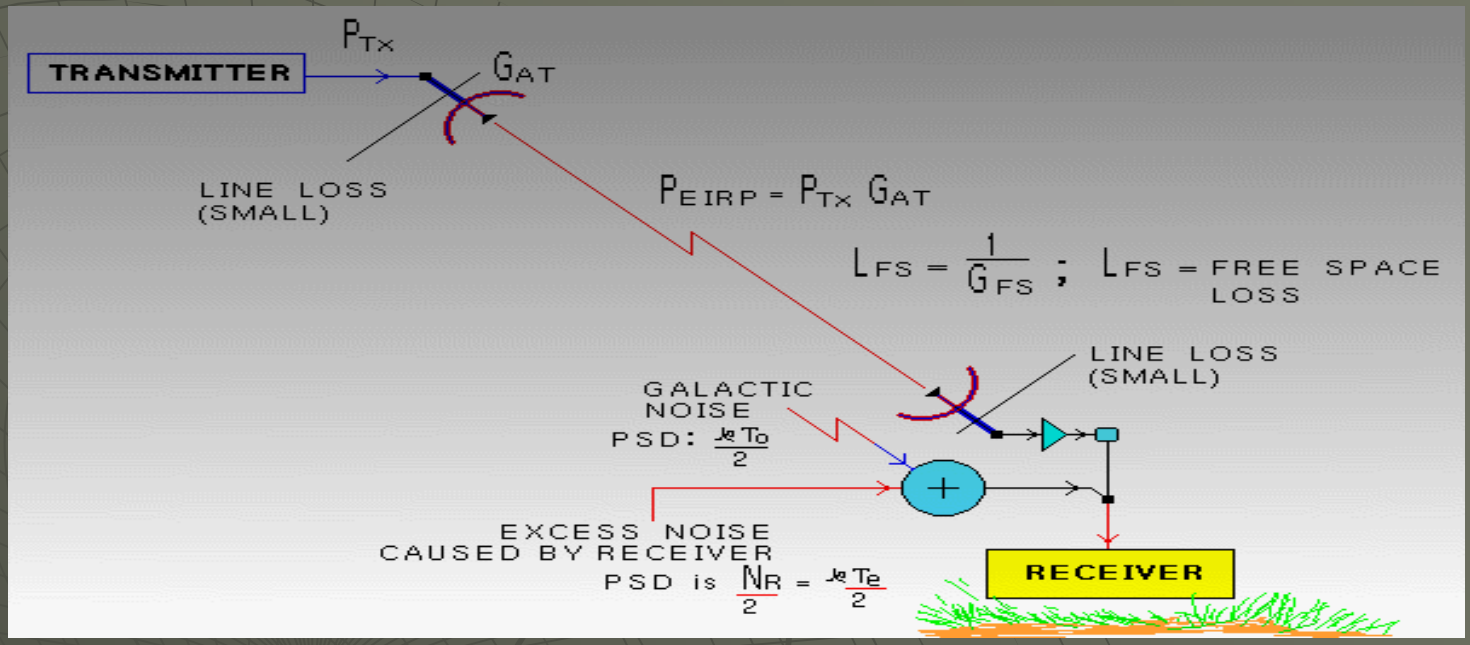


Image from LibreCube

Link Budget



- Students will need to calculate a link budget to determine what is needed for power and receive sensitivity
- It is an accounting of all gains and losses from the transmitter, through the medium, to the receiver

Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) – Losses (dB)

Free Tools (Suggested by LibreCube)

- Office Tools
  - Open Office: https://www.openoffice.org/
  - Libre Office: http://www.libreoffice.org/
- Mechanical Design
  - FreeCad: http://www.freecadweb.org/
  - Blender: http://www.blender.org/
- Electrical Design
  - KiCad: http://www.kicad-pcb.org/display/KICAD/KiCad+EDA+Software+Suite
- Signal processing
  - GNU Radio: http://gnuradio.org/redmine/projects/gnuradio/wiki

Antenna and Deployment Systems

Challenges:

- Before deployment system must still fit inside the CubeSat dimensions (10cmx10cmx10cm)
- Material must withstand temperature changes and mechanical forces
- Must be as light as possible

- Common antenna material is from a tape measure
- Common deployment method is to melt a retaining nylon thread releasing the tape measure antenna

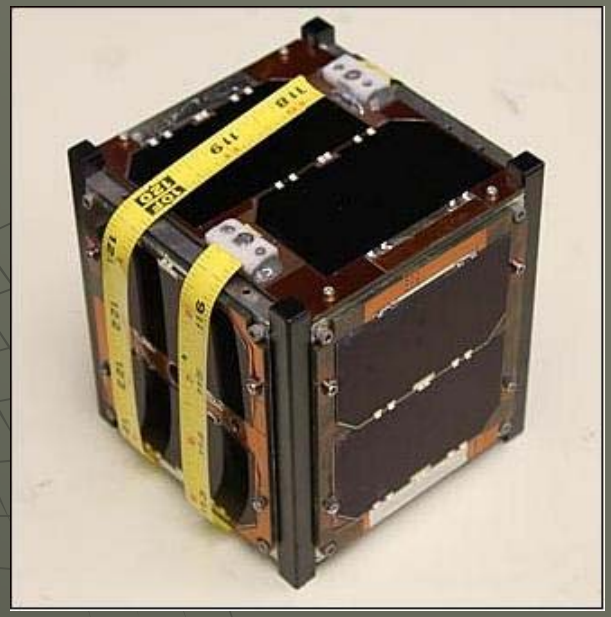


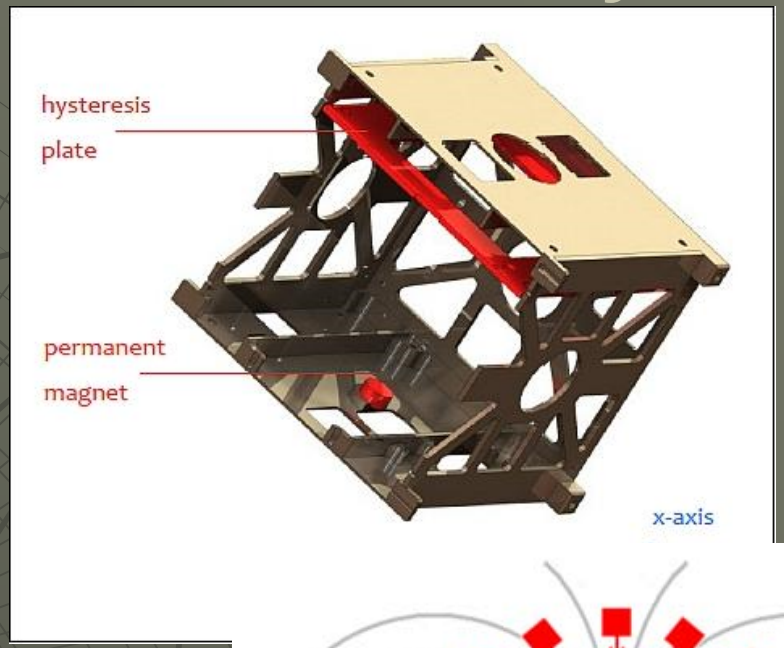
Image of M-Cubed from eoportal.org

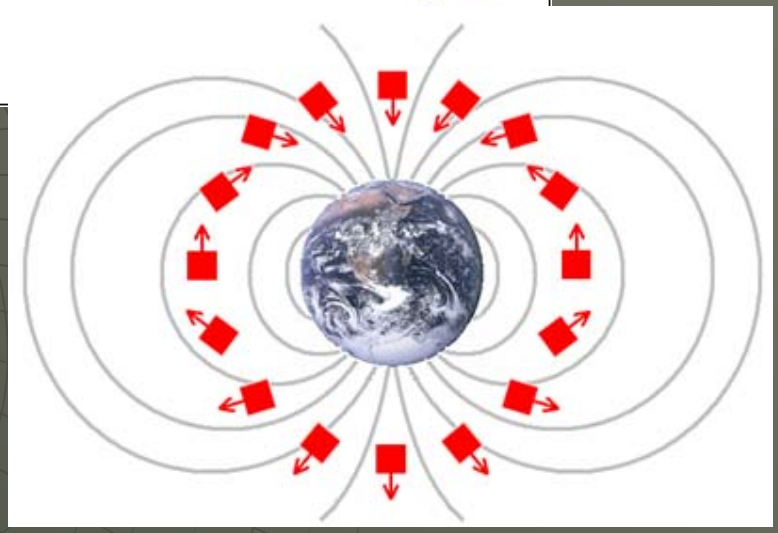
Passive Attitude Control System

Use fixed magnets to keep the CubeSat in a fixed orientation relative to the Earth's magnetic field

CubeSat drawing from eoportal BEESAT-2 and 3

Magnetic Field image from M-Cubed (University of Michigan)



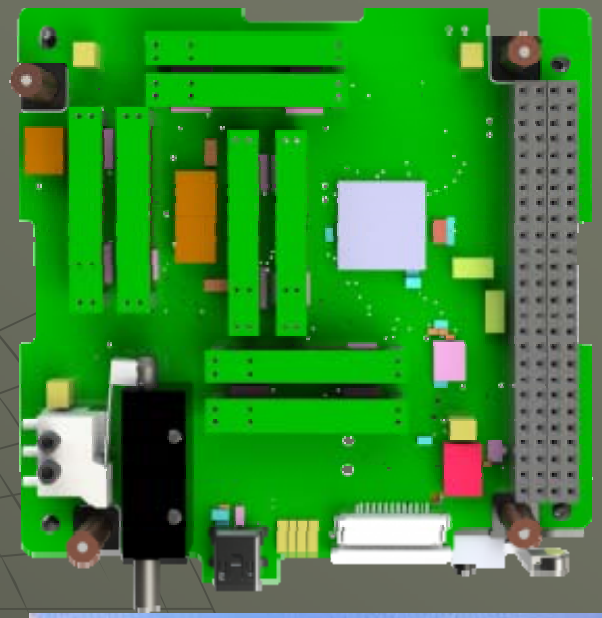


Active Attitude Control System

ADCS: Attitude Determination and Control System

- The orientation of the CubeSat is determined using
  - A magnetometer
  - Knowledge of the earth's magnetic field
  - Knowledge of the CubeSat's location
- Activate electromagnets (Magnetic Torquers) to push against the Earth's magnetic field

Image and information from Space Systems Engineering (University of Alaska)



Vibration Testing

Improvisation:

- No shake table? Try a random orbital sander and a variable speed control
- Mount ono a very stable base
- Can set 10 Hz to 150Hz

Idea from “Surviving Orbit the DIY Way” – Sandy Atunes

Image from “Surviving Orbit the DIY Way” – Sandy Atunes and Amazon

Temperature and Vacuum Testing

Improvisation:

- No temperature or vacuum chamber? Try a pressure cooker, a vacuum pump, and dry ice
- Idea from "Surviving Orbit the DIY Way" – Sandy Atunes

Image from "Surviving Orbit the DIY Way" – Sandy Atunes

Flight Testing

Improvisation:

- No vehicle to launch to orbit?
- Use a large amateur rocket to get to 1-2 miles
  - Tests ability to withstand high "g"s
  - Tests deployment of antennas
  - Tests communications
  - Tests batteries and solar panels (for a short period)

Flight Testing

Improvisation:

- No vehicle to launch to orbit?
- Use a high altitude balloon to launch to 100K feet or higher
  - Flight is longer than amateur rocket
  - Payload will experience some vacuum and cold
  - Good test of communications and tracking

Photos from Sparkfun

Mechanical Constraints

1U CubeSat Acceptance Checklist

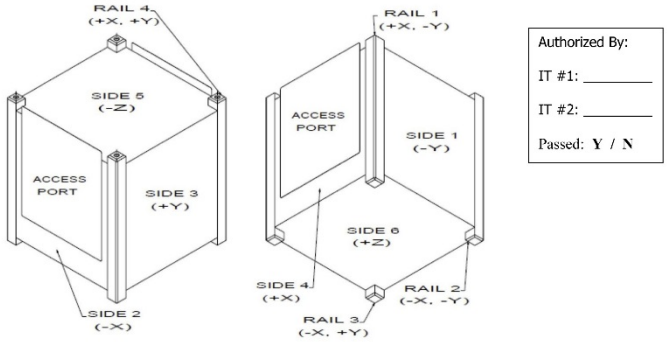
Project: Date/Time: Engineers:

Organization: Location:

Satellite Name: Satellite S/N: *Revision Date: 02/20/2014*

Mass (< 1.33 kg)	_____	**RBF Pin** (≤6.5mm)	_____
Spring Plungers (Depressed)	Functional Y / N Flush with Standoff Y / N	**Rails Anodized**	Y / N
Deployment Switches (Depressed)	Functional Y / N Flush with Standoff Y / N	**Deployables Constrained**	Y / N

Mark on the diagram the locations of the RBF pin, connectors, deployables, and any envelope violations.



Authorized By:

IT #1: _____

IT #2: _____

Passed: **Y / N**

List Item	As Measured				Required
Width [x-y]	Side 1 (-Y)	Side 2 (-X)	Side 3 (+Y)	Side 4 (+X)	
+Z	_____	_____	_____	_____	$100.0 \pm 0.1mm$
Middle	_____	_____	_____	_____	$100.0 \pm 0.1mm$
-Z	_____	_____	_____	_____	$100.0 \pm 0.1mm$
Height [x-y]	Rail 1 (+X, -Y)	Rail 2 (-X, -Y)	Rail 3 (-X, +Y)	Rail 4 (+X,+Y)	
	_____	_____	_____	_____	$113.5 \pm 0.1mm$
	Rail 1 (+X, -Y) length x width	Rail 2 (-X, -Y) length x width	Rail 3 (-X, +Y) length x width	Rail 4 (+X, +Y) length x width	
+Z Standoffs	____ x ____	____ x ____	____ x ____	____ x ____	$\geq 6.5mm$
-Z Standoffs	____ x ____	____ x ____	____ x ____	____ x ____	$\geq 6.5mm$
Protrusions	Side 1 (-Y)	Side 2 (-X)	Side 3 (+Y)	Side 4 (+X)	Side 5 (-Z)	Side 6 (+Z)	
	_____	_____	_____	_____	_____	_____	$\leq 6.5mm$

Photo from PE0SAT

The P-POD (Poly Picosatellite Orbital Deployer) is a common deployment method at launch – and comes with strict mechanical constraints

Launch Opportunities

- Demand is increasing
- Commercial services are increasing
- Secondary payload opportunities are increasing
- Free and extremely low cost launch opportunities are decreasing
- NASA CubeSat Launch Initiative lets CubeSats hitch a ride
- InterOrbital sells kits and launch opportunities
- Check with Cal Poly

Image from Seradata

Standards, & Suggestions

Specifications:

- List available at: http://www.cubesat.org/index.php/documents/developers
- CubeSat Design Specification: http://www.cubesat.org/images/developers/cds_rev13_final2.pdf
- Acceptance checklist: http://www.cubesat.org/images/developers/cac_forms_rev13cds.pdf
- RF Licensing Process Overview: http://www.cubesat.org/images/developers/licensing/rf_licensing_overview.pdf
- Amateur bands allocated to amateur-satellite: http://www.itu.int/en/ITU-R/space/AmateurDoc/AmateurSatServiceFreq.pdf

Suggestions (Possible Starting Points):

- Board Interface and Electrical Bus (LibreCube): https://github.com/open-source-cubesat/LCBS/blob/master/LibreCube%20Board%20Specification.pdf
- Telemetry message formats:
  - European Cooperation for Space Standardization: http://www.ecss.nl/
  - Consultative Committee for Space Data Systems: http://public.ccsds.org

Thank you

Questions?