The laser-communicating 2U Cubesat with 10bps data rate capability from the trans-lunar orbit

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Presentation contents

Selecting an application area for radio and laser communicators

Parameter	Radio (x-band)	Laser (red)
Transmitter power consumption	+38 dBm	+38 dBm
Transmitter efficiency	-5 dB	-3 dB
Transmitter antenna gain	21 dB	76 dB
Ground station gain	21-53 dB	106 dB – 116 dB
Receiver sensitivity (at 10 bps)	-150 dBm	-108 dBm
Zero distance link margin	204 – 236 dB	325 – 335 dB
Communication distance (at 10 bps)	**0.6 – 25 mln. km**	**4 – 14 mln. km**

From table above, one can conclude what the RF communications are superior in high-end, professional systems, but laser communicators are better for low-cost or low-weight, amateur systems

	Laser communicators	Radio communicators
Main merit	High gain in simple package, both in space and on ground	Good receiver sensitivity
Main demerit	Bad receiver sensitivity	High gain can be reached only on ground, for high cost

Making a useful satellite communicator

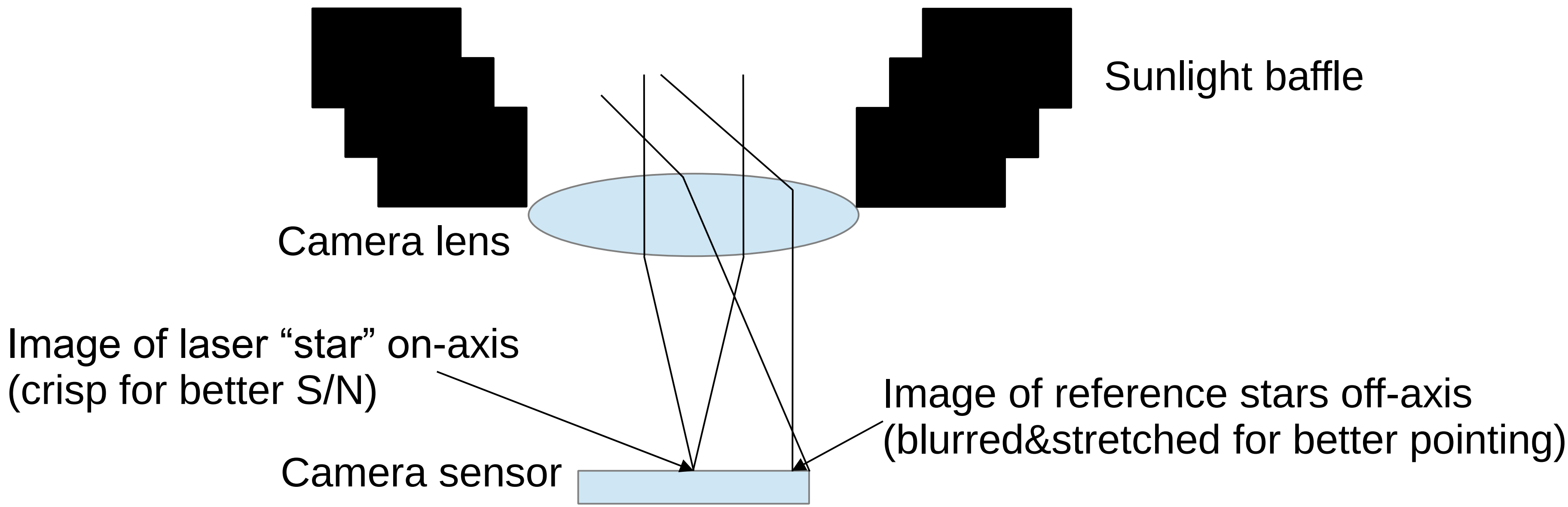
Components of useful communication system
Sufficient data transfer rate
Data transfer reliability
Data medium accessibility
Hardware accessibility
Tracking availability

Radio communicator	Laser communicator
Up to 1 Mbps is routine	Standard for data transfer rates are not established
90% up-time	10% - 40% up-time
Radio license required, licensing enforced	Licensing neither exist nor enforceable
Hardware, especially for ground stations, is not easily available, lending and sharing required	High-performance hardware is easily available
Ranging is easily implementable, but direction finding require very expensive hardware	Ranging and direction finding are easily implementable. No standards established.

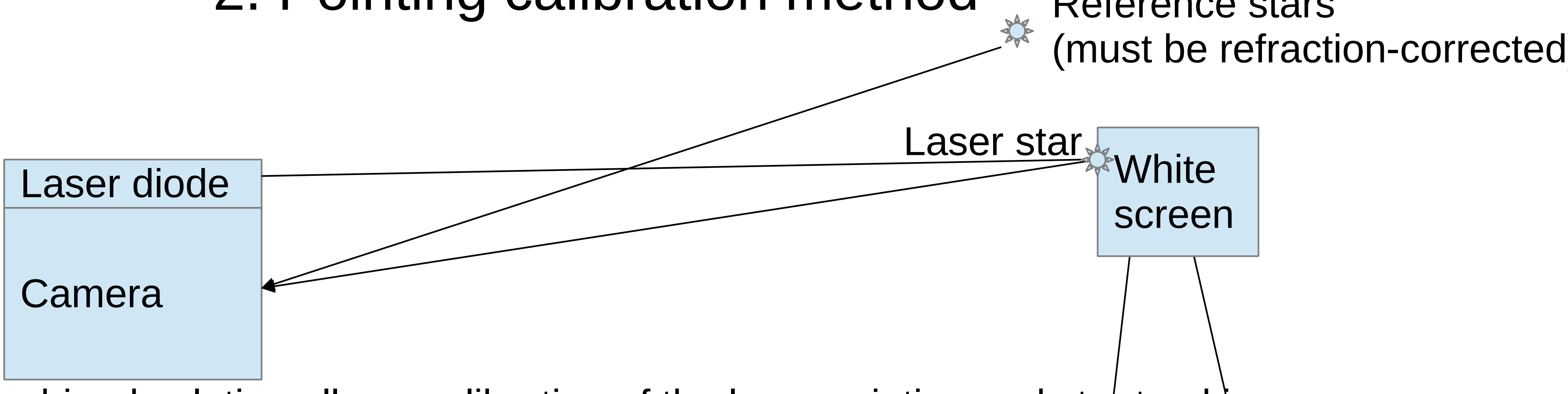
Solutions specific of satellite laser communicator

1. Dual-function components

Star tracker camera (soft focus) + Laser receiver camera (hard focus) = Combined receiver camera (hard focus with field curvature)



2. Pointing calibration method



Combined solution allows calibration of the laser pointing and star tracking error on-ground
by creating “laser star” on sufficiently remote surface (>20 m distance)

Known problems of laser communication

1. Atmospheric scincillation. It cause variability of light measured light intensity, significantly (~10dB) degrading link S/N. Because of place, time and telescope system dependence of scincillation amplitude, more experiments are needed. Larger telescopes are strongly affected, but telescopes with lens about 100mm are less sensitive to scincillation

2. Light pollution. Generally, effective tracking is not possible near or in the large cities, as well with the full moon above horizon. The downlink is less affected, but further experiments are necessary to quantify the seriousness of problem

3. Satellite laser transmitter pointing. Reaction wheels are required, but existing models are very expensive (~20000 USD/axis) and poorly fit in the CubeSat. Additional development required

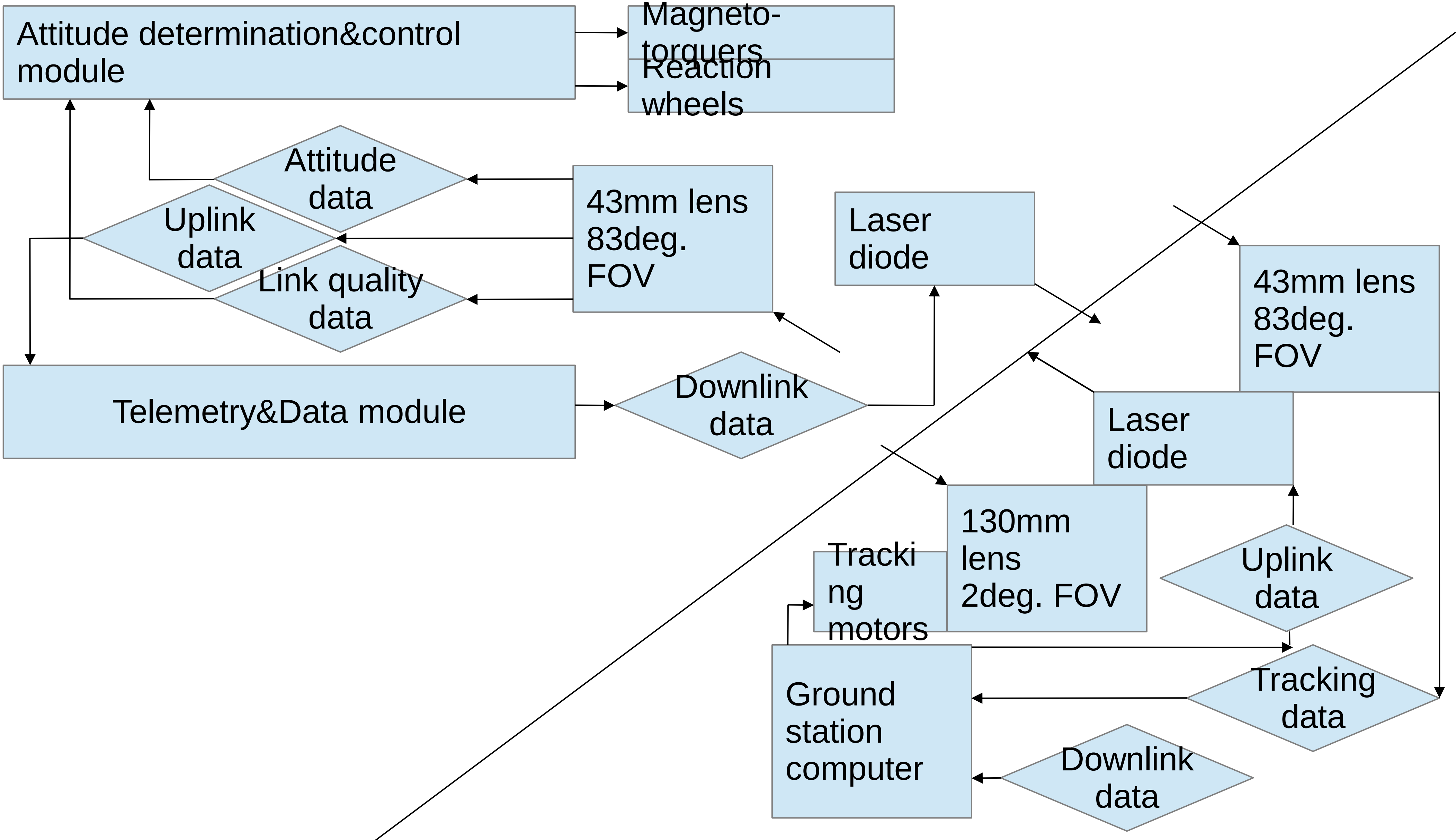
4. Momentum dumping. For highly-elliptical orbit, the magnetotorquers can be used as proposed here. But for Lunar orbit an alternative propulsion system compatible with CubeSat must be used

5. Weather sensitivity. Can be alleviated by making ground station mobile and low-cost, so temporary stations can be deployed according to weather forecasts. Need to tested to assess the plausibility. Regional features (deserts) can be a bonus of laser communication usage.

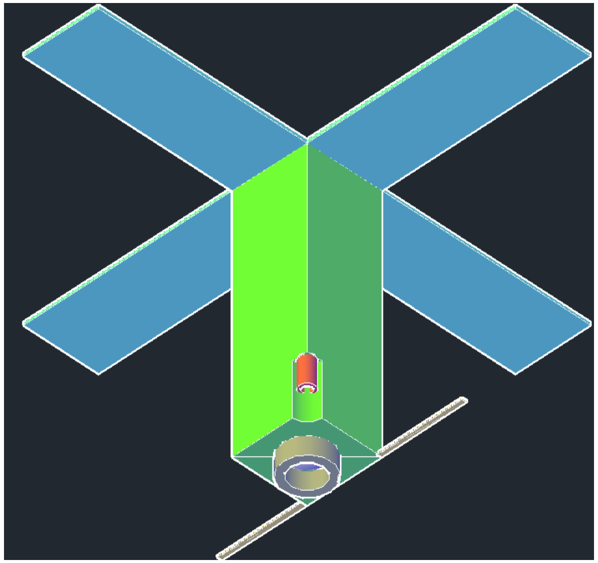
6. The automatic ground station detection, identification and pointing. Required software is expected to be extremely complex.

7. Atmospheric refraction. The model of the atmospheric refraction must be generally 0.1 arcmin. accurate to work with the modern laser pointers, which is within the error of Bennett/Saemundssen model. But higher accuracy may be required in future

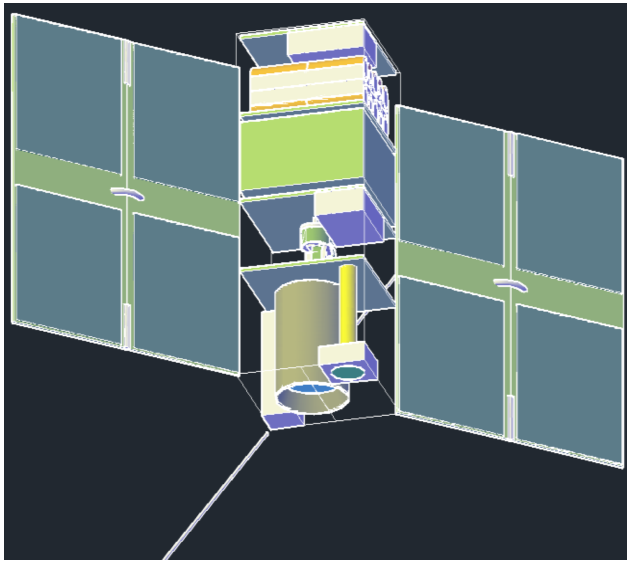
Communication diagram of the CubeSat with laser communicator



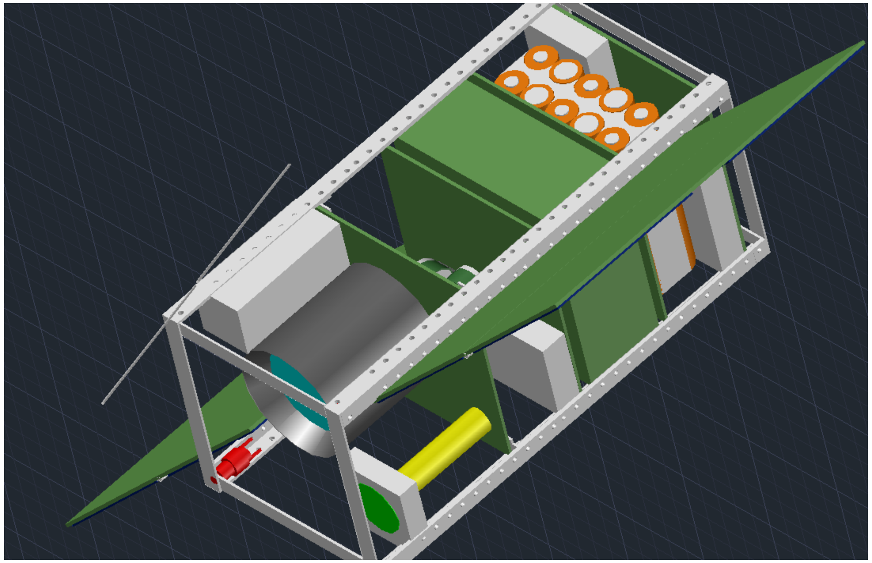
The progress of developing Cubesat with laser communicator



June, 2014: initial concept, 3U size



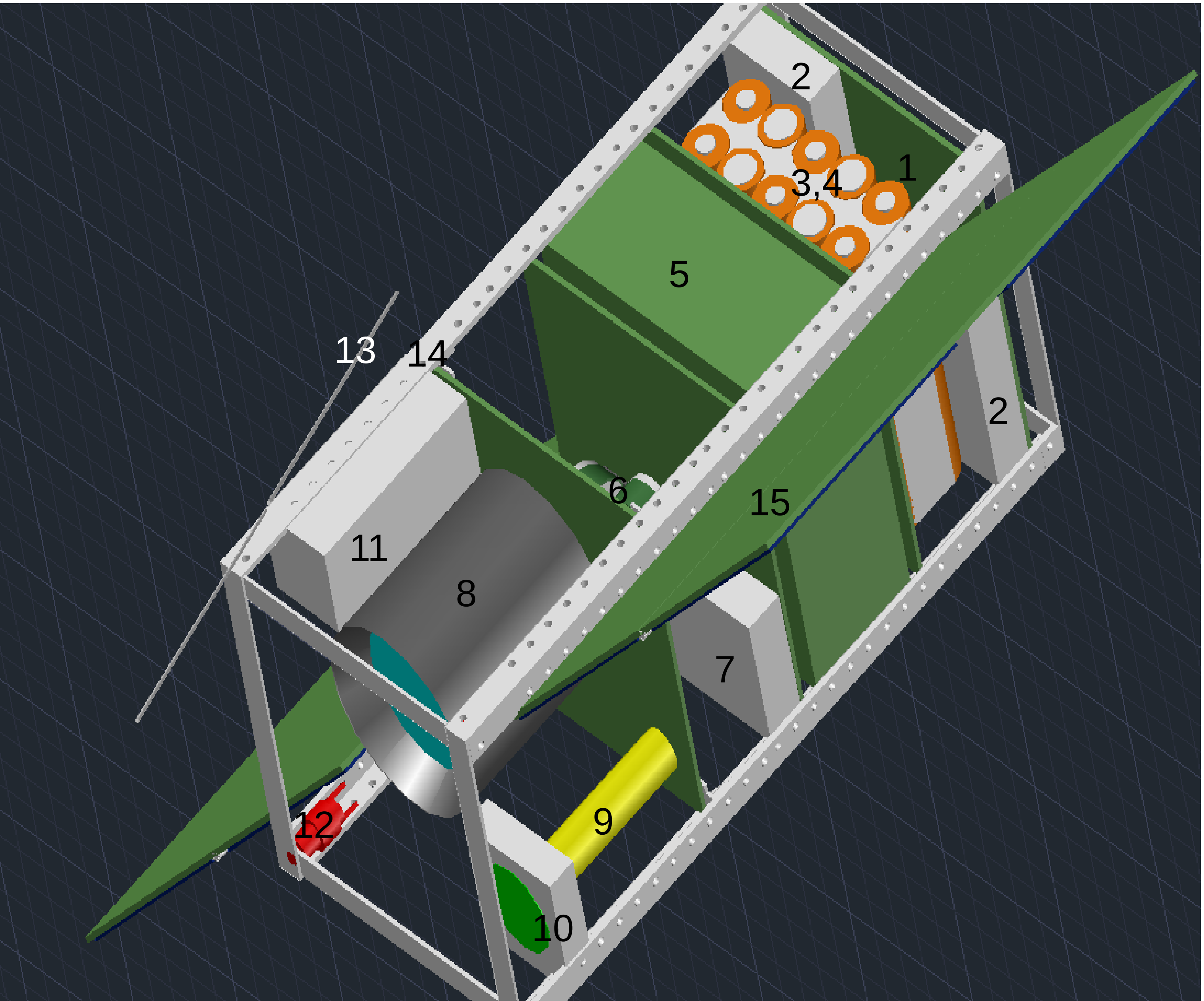
October, 2014: 2U size, preliminary design of power subsystem



November, 2014: preliminary design of mechanical subsystem and deployment switches

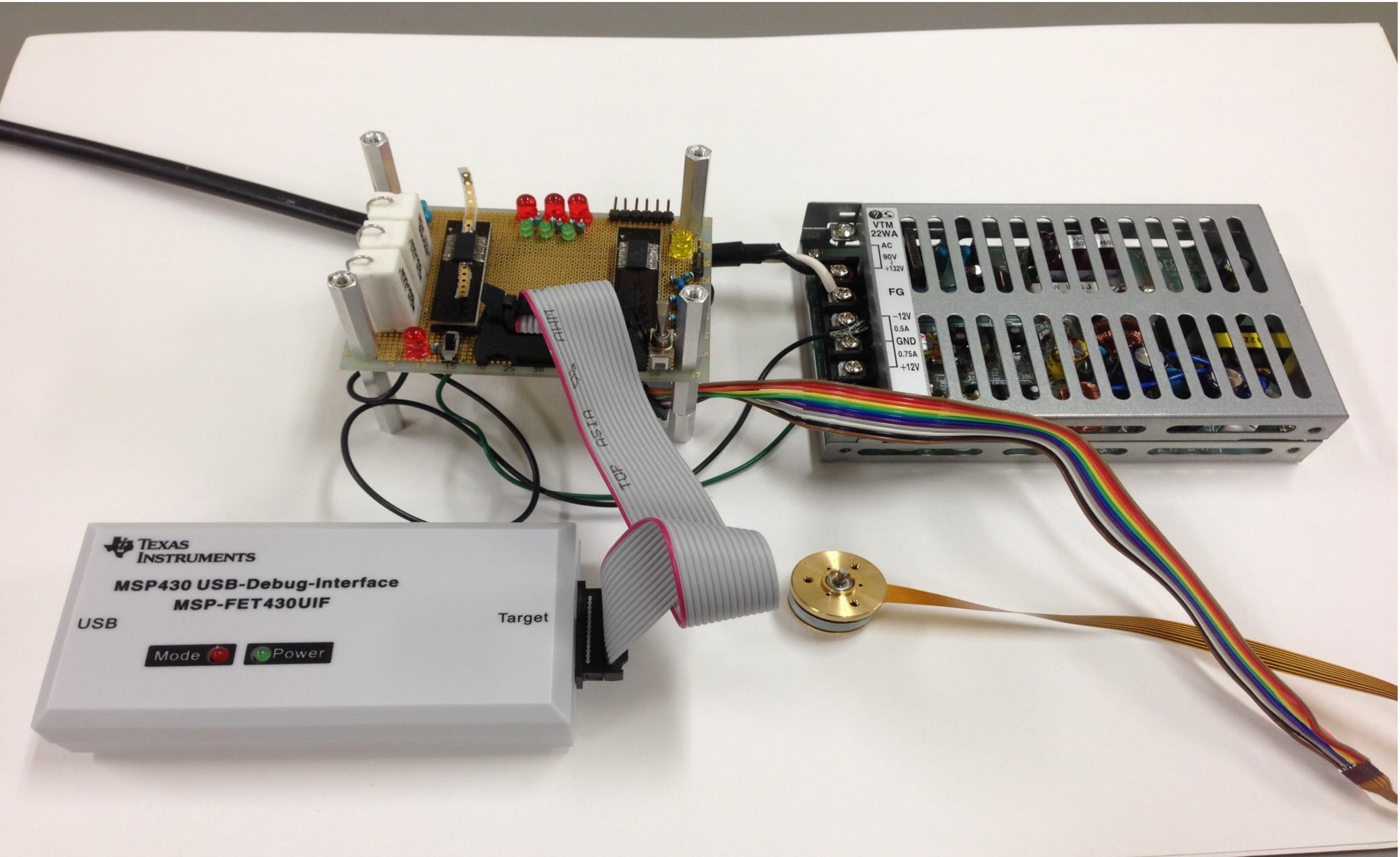
Component	Volume, cm^3	Volume, %
Internal PC/104 stack (payload)	1939	66.9
Cubesat rails and brackets	36	1.2
P-POD rails and corners	139	4.7
Large side bays (for solar panels)	443	15.2
Small side bays	332	11.4
Other	9	0.3
Total volume in P-POD launcher	2899	100

Block diagram of proposed Cubesat with laser communicator



1 – main radiator
2 – electric power modules
3 – battery pack
4 – survival heater
5 – command&data module
6 – reaction wheels
7 – attitude control module
8 – wide-field camera
9 – laser diode
10 – laser collimator lens
11 – 430 MHz transceiver
12 – deployment switches
13 – 430 MHz antenna
14 – mounting brackets
15 – solar panels

Reaction wheel programming prototype



Current status: 2 prototypes RW hardware ready, 1 was sent to USA for software development by volunteer

Appendix.
Budgets of proposed Cubesat

1. Mass/Volume/Power budget
2. Laser communicator link budget (simplified)
3. 430 MHz communicator link budget
4. The Cubesat with laser communicator - Current development status

Mass/Volume/Power budget

Details

Component	X	Y	Z	m, g	duty	P, W	N	Pt, W	Vt, cm3	Mt, g
Body solar panel	100	200	2	69	0	4.100	2	0.0	80.0	138
Stub solar panel	200	200	2	190	1	8.200	2	16.4	160.0	380
Solar panel diode	10.4	15.4	4.4	2	0	0.000	6	0.0	4.2	12
DC-DC converter	57.9	36.8	12.7	63	-0.085	-0.697	2	-1.4	54.1	126
Battery pack (NiMH)	86	85	19	618	-0.15	-1.125	2	-2.3	277.8	1236
Bus crossbar	7.62	7.12	3.65	0.4	-0.05	-0.002	8	0.0	1.6	3.2
Load isolation diodes	10.4	15.4	4.4	2	-0.6	-0.032	20	-0.6	14.1	40
Charger IC module	22	25	8	7	0.45	-1.200	2	-1.1	8.8	14
Thermal shields, 0.2mm Al	223	96	0.2	46.2	0	0.000	4	0.0	17.13	185.0
Survival heater	92	95	1	4.5	0.45	-3.000	1	-1.4	8.74	4.5
Laser+lens	35	35	60	51	0.5	-1.500	1	-0.8	73.5	51
Flight computer	92	95	50	240	1	-0.300	1	-0.3	437	240
Radio beacon	25	25	60	85	1	-2.500	1	-2.5	37.5	85
camera	60	60	60	342	1	-0.400	1	-0.4	216	342
reaction wheels	33	32	20	117	1	-1.800	1	-1.8	21.12	117
sun sensor suite	15	80	5	25	1	-0.200	2	-0.4	12	50
torquers assembly				32	0.1	-3.000	2	-0.6	21	64
Deployment switches	9.5	9.5	25	1.5	0	0	2	0.0	4.51	3
Separation springs	7	7	18	1	0	0	2	0.0	1.76	2
Sun sensor corner type	8	8	14	0.7	1	-0.03	2	-0.1	1.79	1.4
Radiator, 1mm Al w. paint	98	98	1.2	0			3	0.0	34.57	93.4
PC/104 PCBs	96	90	1.6				3	0	41.47	76.7

Summary

Satellite fill factor and mass, g		0.73	3176.4
Power margin BOL, %	**30.0**		
Battery lifetime, h	**5.7**		
Power consumption on bus, W	8.4		

Laser communicator link budget (simplified)

	tracking/uplink	downlink
Peak power available, W	*0.83*	*0.83*
LED luminous effciency, unitless	0.12	0.12
LED directivity, unitless	3.70E+07	3.70E+07
Communication distance, m	400000000	400000000
Power density before atmosphere, W/m2	1.83286382734912 E-012	1.83286382734912 E-012
Atmospheric transmission	0.7	0.7
Camera transmission to pixel	0.9	0.9
Nightglow, watt/steradian	1.28E-06	1.28E-06
Field of view, degrees	83	2
Camera aperture, m	*0.043*	*0.13*
Signal on pixel, W	1.6768667671875E-015	1.532668921875E-014
Nightglow on pixel, W	6.77E-14	3.59E-16
Camera quantum efficiency	3.50E-01	3.50E-01
Single photon energy	2.55831E-019	2.55831E-019
Nightglow related flow, electrons/s	92561	491
Dark current, electrons/s (STAR 250 specs)	4750	4750
Electron noise, electrons	76	76
Orbit altitude, km	400000	400000
quantization, electrons/LSB	35	35
Saturation-limited mode bit-rate multiplier	130	1
S/N, dB	**9.86**	**10.37**
Encoding ratio to reject starlight	0.5714285714	0.5714285714
Shrink ratio to avoid sub-pixels (0.7 if C32<=1)	1	0.7
Average pass duration, s	15265.2395211932	15265.2395211932
Average downlink/pass, bits	**26953**	**153250**
Nightglow margin (5=average pollution)	**5.00E+00**	**5.00E+00**
Maximal bits/frame at ideal conditions	3	2
Data rate, BPS	**1.766**	**10.039**
BER	**0.0018364414**	**0.0009499369**
Dark pixel value, saturation corrected	899	5
Signal pixel value, saturation corrected	921	29

430 MHz communicator link budget

項目	単位	Downlink	Comments	English parameter
周波数	MH z	430.00		Frequency
送信EIRP	dBm	22.56		Transmitter EIRP
送信電力	**dBm**	**24.70**	**1 W at 35%**	Transmitted power
送信アンテナ利得	dBi	1.00		Transmitter antenna gain
送信フィーだ損失	dB	-0.14		Transmitter feeder loss
送信ポインチング損失	dB	-3.00		Transmitter pointing loss
自由空間損失	dB	-146.60		Free space loss
伝播距離	km	1193.00	20deg. Elev.	Max. distance
軌道高度	km	500.00		Orbit altitude
仰角	deg	20.00		Minimal elevation
各種損失	ｄB	-0.13		Various losses
編波損失	ｄB	-0.03		Polarization loss
大気吸収損失	ｄB	-0.02		Air absorption loss
降雨損失	ｄB	-0.08	5 mm/h rain	Rain scattering loss
その他損失	ｄB	0.00		Other losses
受信G/T	dB/K	-13.29		Receiver G/T
受信アンテナ利得	ｄB	8.21	0.9	Receiver antenna gain
受信フィーだ損失	ｄB	0.30		Receiver feeder loss
受信ポインチング損失	ｄB	-0.10		Receiver pointing loss
システム雑音温度	ｄBK	21.70	Tn=150K (怪しい！)	System noise temperature
受信電力	ｄBm	-115.96		Received signal power
雑音電力密度	ｄBm/Hz	-177.00		Noise spectral density

The Cubesat with laser communicator - current status

Task	Interval	Merit	Difficulty	Cost,万円	Complete
Feasibility study	4/2014-7/2014	n/a	none	0	100%
2U CubeSat bus and standard parts	4/2015-11/2015	0%	Low	330	10%
Reaction wheels	9/2014-2/2015	30%	Medium	50	25%
Camera and sensors	2/2015-6/2016	90%	High	180	5%
PCBs, jigs, custom parts	9/2014-9/2017	15%	Low	6	5%
Laser and collimator	8/2015-6/2016	90%	Medium	35	10%
Glue-logic FPGAs	4/2016-12/2016	0%	Low	16	0%
Ground telescope with tracking	4/2016-6/2016	n/a	Low	28	0%
CubeSat engineering model: spare parts, repairs, rework	8/2014-8/2016	n/a	Medium	130	0%
CubeSat flight model: spare parts, repairs, rework	9/2016-9/2017	n/a	Low	45	0%
Ground testing	6/2015-8/2017	n/a	Medium	unknown	0%
Software	9/2014-9/2017	n/a	High	0	1%
Launch	5/2018	n/a	n/a	unknown	n/a
Budget overrun margin of 25%				205	n/a
Total	4/2014-5/2018			1015	5.2%