Power Budget for 1U Satellite

BIRDS,EPS

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CubeSat & BIRDS Satellite project

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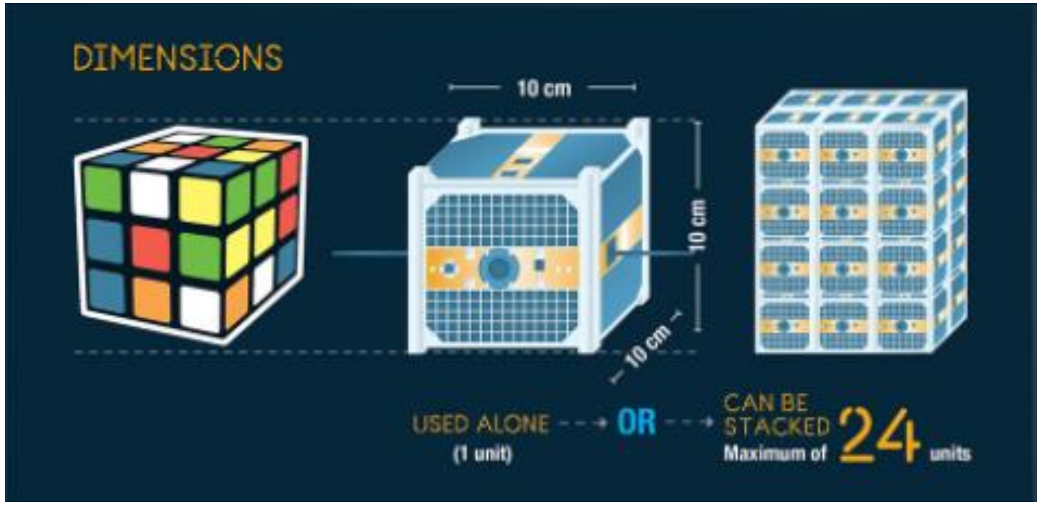
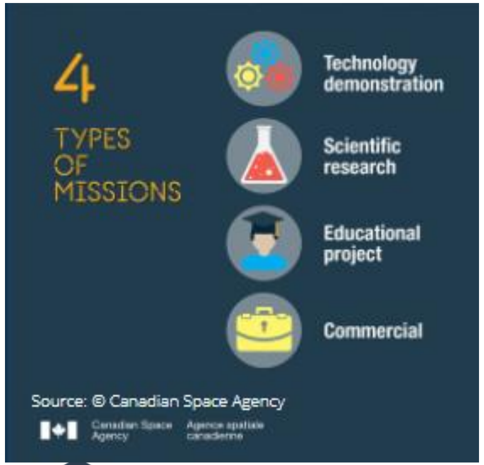
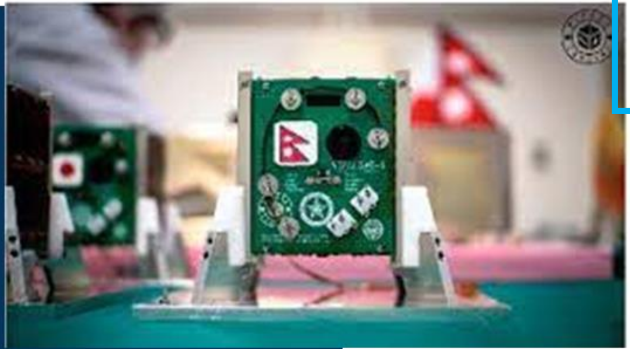




FEATURE	SPECIFICATION
STANDARD	CUBESAT
DIMENSIONS	1U (113.5X100X100) MM
WEIGHT	1 KG (1.3KG)
HARNESS	BACKPLANE TYPE



BIRDS-3 (NepaliSat-1) satellite

BIRDS project satellites

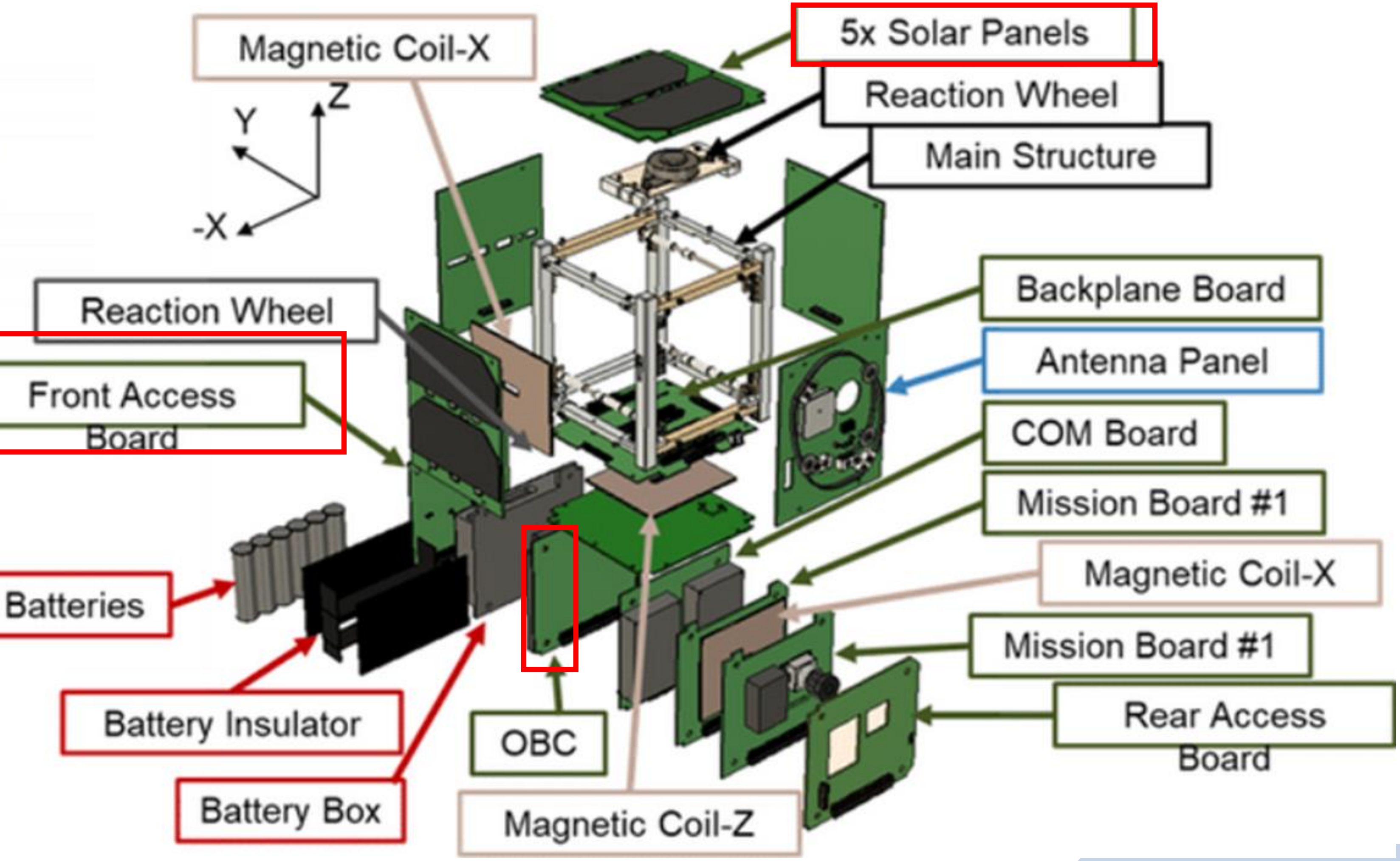
- The Joint Global Multi-Nation Birds Satellite project. acronym as "Birds project."

BIRDS-4
Joint Global Multi-Nation Birds Satellite Project

Source: Canadian Space Agency

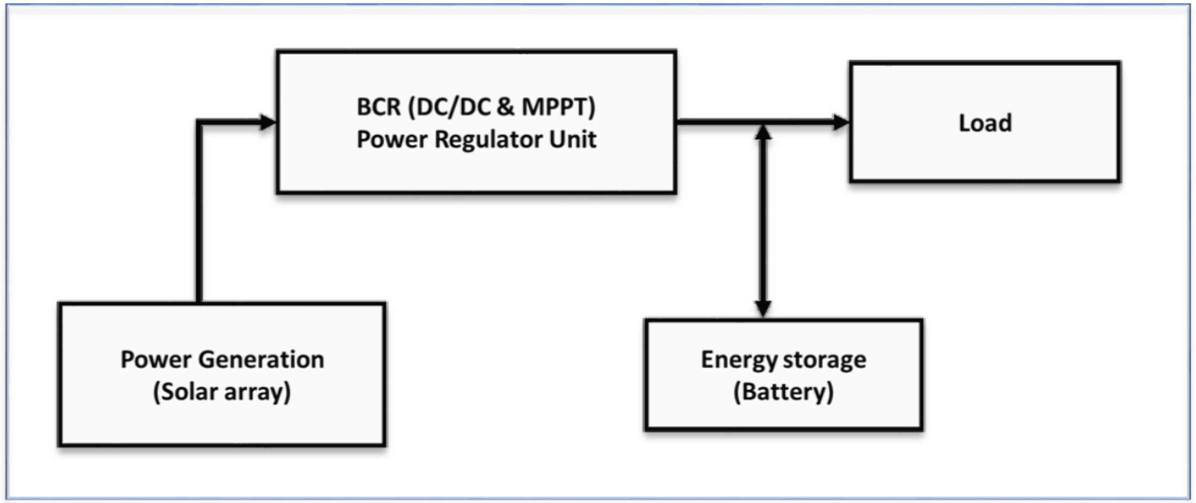
CubeSat Overview and Subsystems

- Antenna and COM board
- Structure
- EPS
- OBC
- Payloads(CAM, ADCS,LoRa. etc



BIRDS CubeSat's EPS system

Electrical Power system (EPS) is a subsystem that has functions to provide uninterrupted power to all on-boards CubeSat electronics both in sunlight and in eclipse.



EPS block diagram

Functions

1.Power Generation

- Generate Power from 5 unit of Solar panels

2.Energy Storage

- Store the Excess power into 3S2P Ni-MH batteries

3.Power Management & Distribution

- Convert the Battery Voltage in to +5V and +3.3V and Unreg levels
- Supply Unregulated line, +5V and +3.3V to the Subsystems and OBC through ON/OFF controlled and overcurrent protected Lines

$$P\ LOAD = (\eta\ BCR * P\ GENmax) \pm PSTOR$$

- Solar arrays are connected to Battery through Peak Power Tracking controlled regulator

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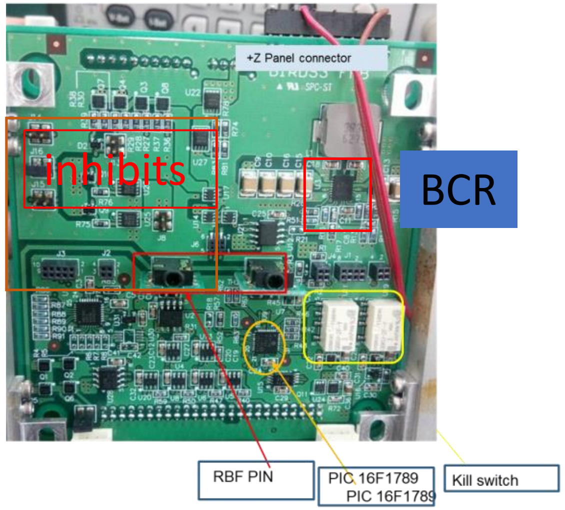
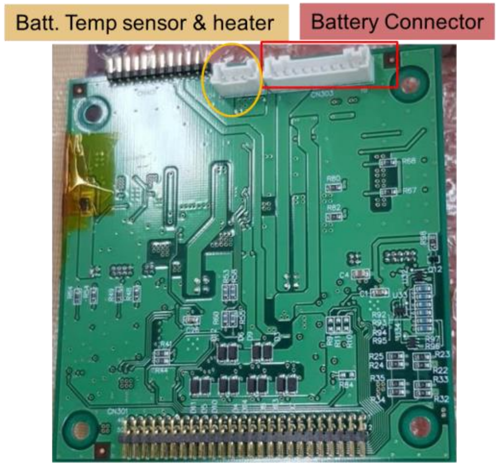
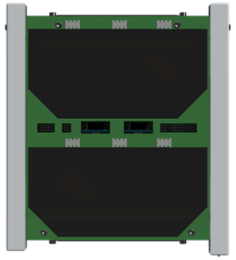
EPS boards and components





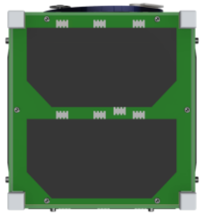
RESET PIC at OBC board

TJ Solar Cell assembly 3G30A	
V max power per cell [V]	2.70 V
I max power per cell [A]	0.504
efficiency	0.293
area [m2]	0.003018



+ Y

$\pm X$



$\pm Z$

Batteries parameters	
Capacity per cell [mAh]	1900
Voltage avg. per cell [V]	1.2
weight per cell [g]	26.25
size per cell [mm]	14.10X 50.10
configuration	3S2P
Voltage total [V]	3.6
Total capacity [mAh]	3800
Initial Energy capacity of battery pack[Wh]	**13.68**

Eneloop NiMH battery

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Power budget analysis procedures

A CubeSat's power budget defines

- power budget describes the balance between the generated power by the solar arrays and the consumed power by the loads on per orbit or per day.

Power profile,

Power consumption by satellite ≤ Solar panel power generation

DEFINE

Test and analysis procedures:
1, MATLAB simulation power generation
2, Power consumption measurement (Each mission board and subsystem)
3,BIRDS-4 Flight data analysis
4, BIRDS-4 EM satellite ground test

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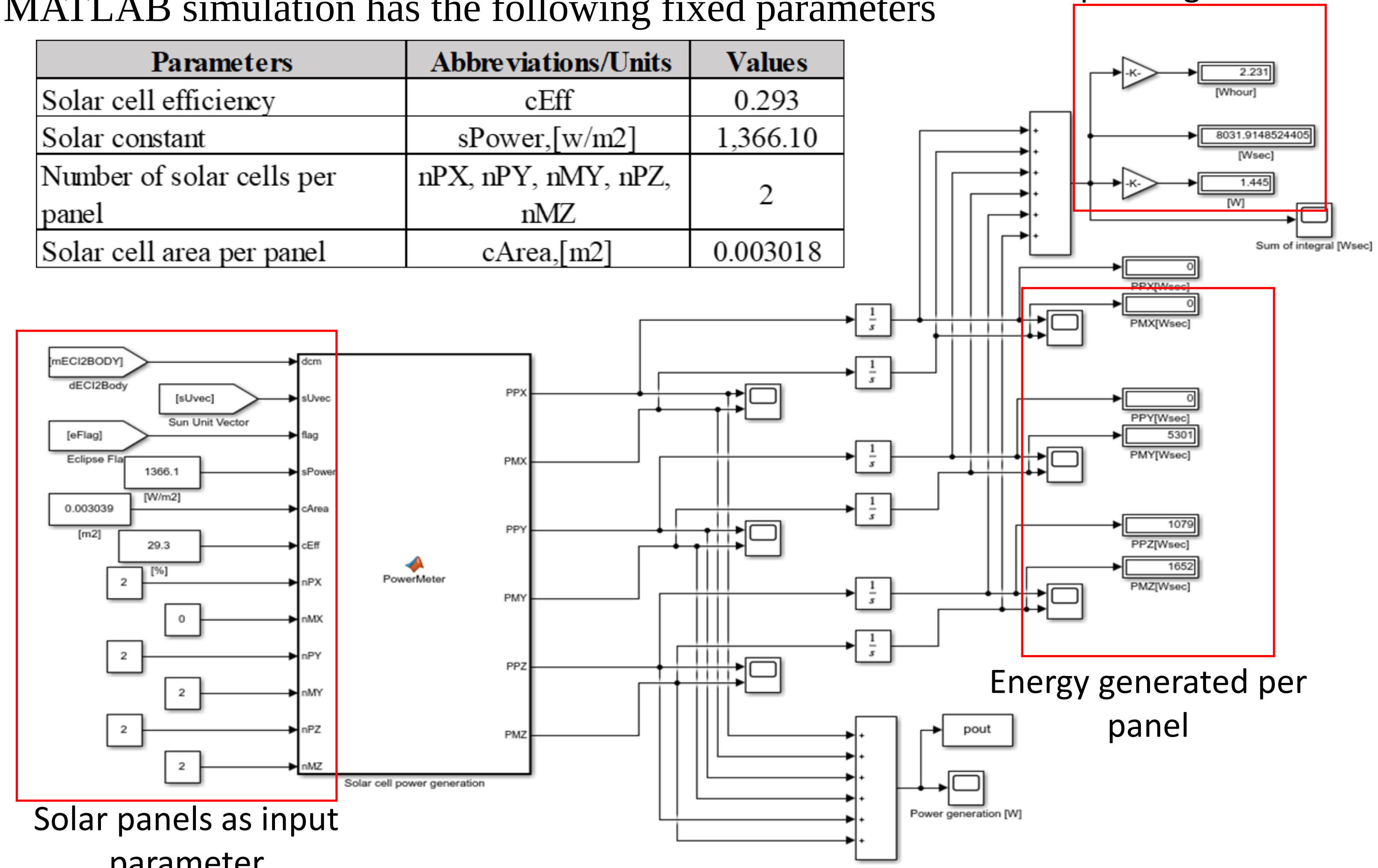
Power generation simulation using MATLAB (1/2)

- There were three simulation conditions considered:
  1. when all 5 panels are working
  2. when 4 panels are working (no -X)
  3. when 3 panels are working (no +Z and -X)
- Based on the conditions, MATLAB shall output total energy and power generated for a 90-minute orbit.
- Sunlit and eclipse time are considered in the simulation.

MATLAB simulation has the following fixed parameters

Parameters	Abbreviations/Units	Values
Solar cell efficiency	cEff	0.293
Solar constant	sPower,[w/m2]	1,366.10
Number of solar cells per panel	nPX, nPY, nMY, nPZ, nMZ	2
Solar cell area per panel	cArea,[m2]	0.003018

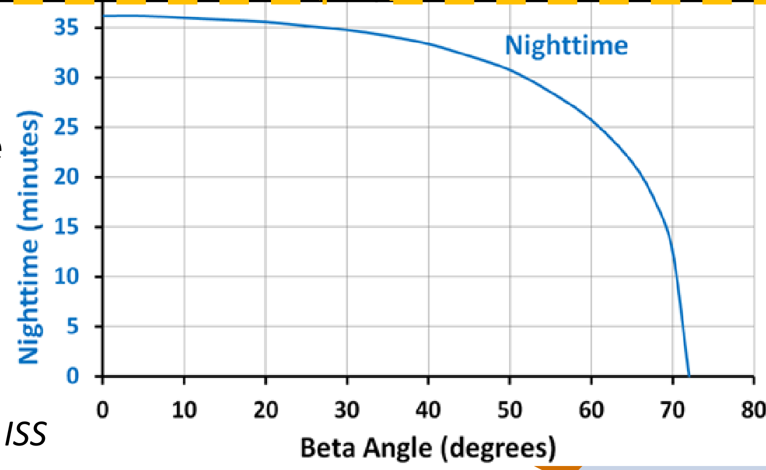


Power generation simulation using MATLAB (2/2)

Parameters	Unit	Beta angle = 30 deg. Eclipse time = 35 min.			Beta angle = 73 deg. Eclipse time = 0 min.		
Solar panels	-	5	4	3	5	4	3
Total Energy generated, **A** (MATLAB simulation)	mWh	2,173	1,875	1,419	3,447	2,980	2,252
Energy consumed by blocking diodes, **B** (Measured)	mWh	240			360		
BCR efficiency, **C** (Measured)	%	80			80		
Total Energy after BCR, **D** **D = (A-B)*C**	mWh	1,546	1,308	943	2,470	2,096	1,514

NOTE:

- Blocking diodes and buck-boost DC/DC converter (BCR) were characterized to obtain the measured values.



Reference: ISS

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BIRDS-4 Power Consumption (Measured)

- Power consumption per subsystem and per payload were measured
- The duration were subsystem and payload were ON is based on 90-minute orbit
- **At nominal mode, BIRDS-4 satellites energy consumption is at 1,438 mWh**

- Mission boss, CPLD also used at Mission operation not at nominal operation
- Battery heater no need

COMPONENTS	OBC-EPS and FAB	COM UHF (RX)	COM UHF (TX-CW)	COM UHF (TX-Telemetry)	APRS-DP SF-WARD (RX)	APRS-DP SF-WARD (TX)	CAM	TMCR	PSC	HNT	ADCS (Stabilization)	ADCS (MCU and sensors ON)	ADCS (Pointing mode)	GPS	ADCS (Pointing Mode)	Mission Boss	Battery Heater	TOTAL ENERGY CONSUMPTION per Mission (mWh)
Maximum power allocated (mW)	428	144	280	4620	135	1400	300	50	16.5	500	0.75	188	1000	240	467	80	440	
Duration per orbit (h)	1.5	1	0.5	0.13	0.25	0.11	0.017	1.5	1.5	0.25	1	1.5	0.5	1.5	1.5	1.5	0.250	
Energy per Orbit (mWh)	642	144	140	600.6	33.75	154	5.1	75	24.75	150	0.75	282	500	360	700.5	120	110	
Command uplink and Beacon	ON	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	OFF	OFF	OFF	ON	ON	1438
Image and sensor data Downlink	ON	ON	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1527
Camera Mission (mode 1 and 2)	ON	ON	ON	OFF	OFF	OFF	ON	OFF	OFF	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	1213
Camera Mission (mode 3 and 4)	ON	ON	ON	OFF	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON	ON	OFF	OFF	OFF	1791
ADCS Initail Mode	ON	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	OFF	OFF	1987
ADCS Determination	ON	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFf	ON	OFF	ON	OFF	OFF	OFF	1568
ADCS Stabilization	ON	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	OFF	ON	OFF	OFF	OFF	1569
APRS-DP and SF-WARD Mission	ON	ON	ON	OFF	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	OFF	1234
HNT Mission	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF	912
PSC Mission	ON	ON	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	ON	OFF	1071
TMCR Mission	ON	ON	ON	OFF	OFF	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF	ON	OFF	1481
ICU Mission	ON	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	926
Deployment(30 mins)	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	752

Nominal Mode

Power consumption (mWh) and operational status per orbit

Mode

Nominal consumption of other satellites

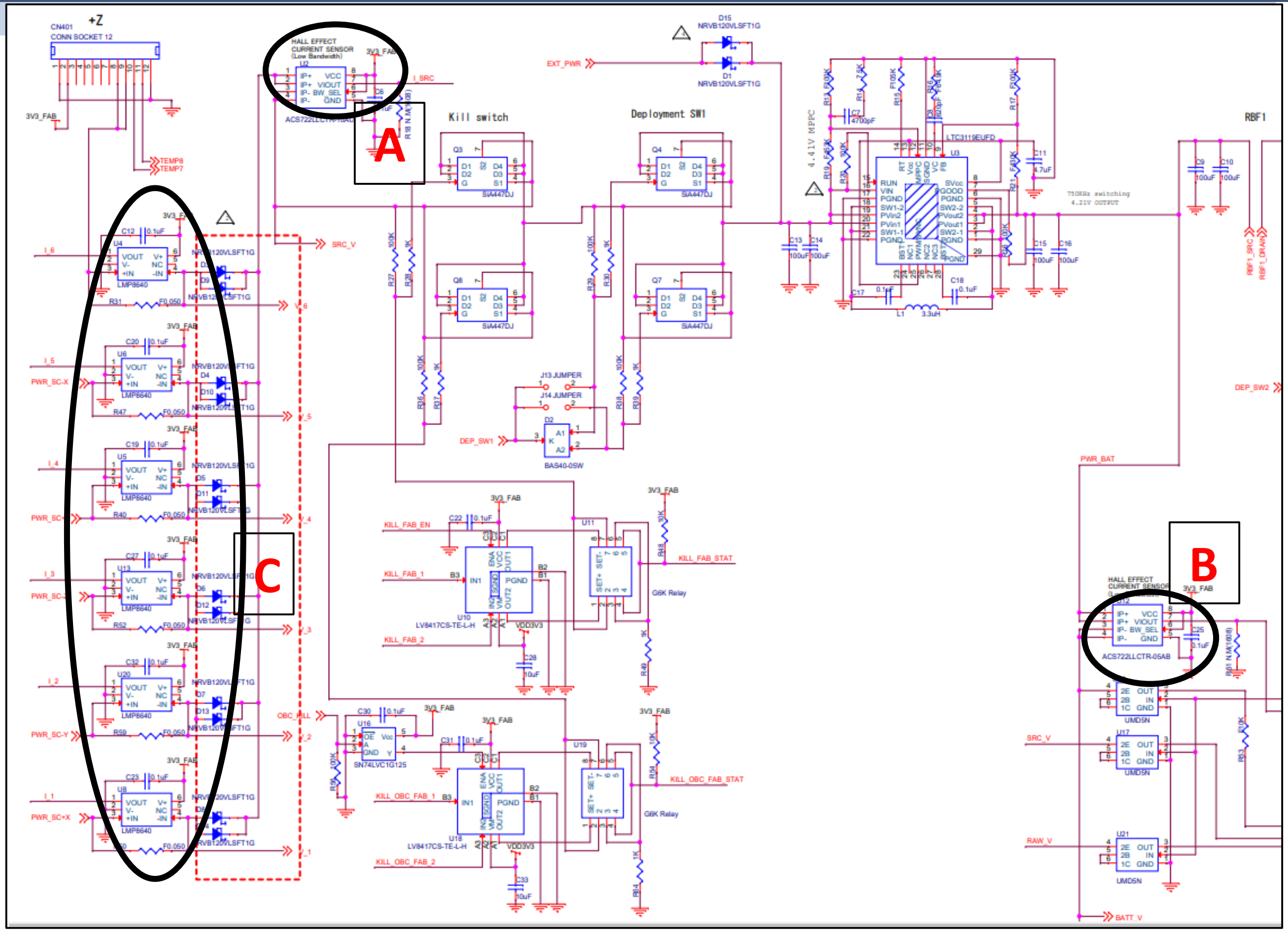
MO-1 satellite

COMPONENTS	OBC-EPS, FAB + COM UHF (RX)	OBC-EPS, FAB + COM UHF(TX-CW)	400MHz LoRa Board	920MHz LoRa Board	TOTAL ENERGY CONSUMPTION per Mission (mWh)
Maximum power allocated (mW)	604.8	987	805	616	
Duration per orbit (h)	1.115	0.418	0.167	0.167	
Energy per Orbit (mWh)	674.35	412.57	134.44	102.87	
Command uplink and Beacon	ON	ON	OFF	OFF	1087

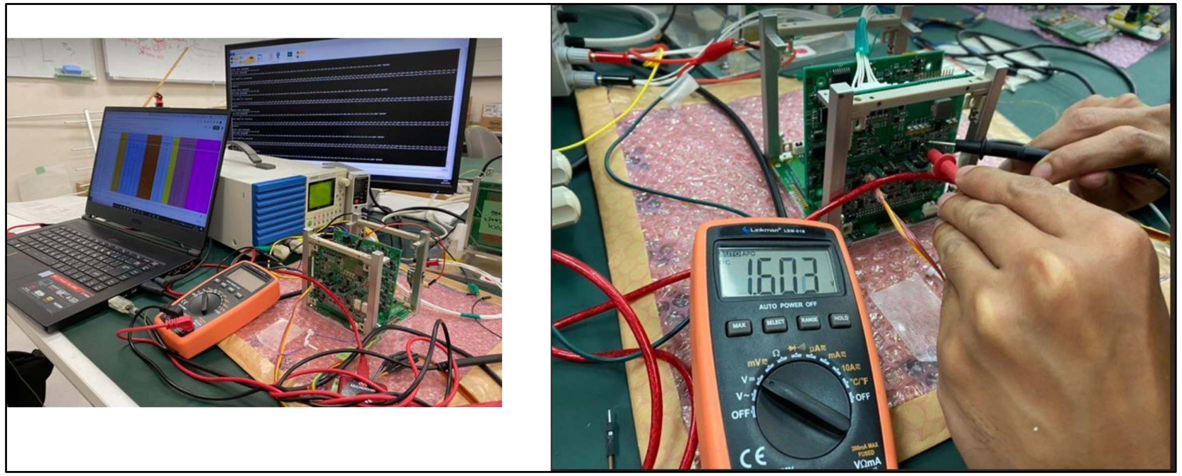
BIRDS-5

	COMPONENTS	OBC-EPS-FAB-COM UHF (RX)	OBC-EPS-FAB-COM UHF (TX-CW)	OBC-EPS and FAB	COM UHF (TX-Telemetry)	APRS-DP SF-WARD (RX)	APRS-DP SF-WARD (TX)	MultiSpec CAM Mission	ICU Mission (With RGB Cam)	ADCS (Determination MCU and sensors ON)	Mission Boss & CPLD	(Antenna Deployment) Burner Circuit	TOTAL ENERGY CONSUMPTION per Mission (mWh)
Power Consumption (mWh) and Operational Status per Orbit	Maximum power allocated (mW)	604.8	987	410	4054.6	280	1710	3200	1321.1	480	123.5	12600 (one time)	
	Duration per orbit/Duty cycle (h)	1.115	0.418	1.53	0.117	0.25	0.11	0.1	0.1	0.25	0.25	2.78×10^{-4}	
	Energy per Orbit (mWh)	674.35	412.57	627.3	474.3882	70	188.1	320	132.1	120.0	30.875	3.5	
	Command Uplink and Beacon	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1086.92
	Image and Sensor Data Downlink	ON	ON	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF	1592.18

Current sensors calibration



BIRDS-4 FAB schematic



- Measurements were taken on the source current sensor (**A**), battery current sensor (**B**), and individual solar panel source current sensors (**C**) with under different temperature conditions: +25 degC, +60 degC, -10 degC
- Based on the measurements, each sensor's HK data formula were updated.

Calibrated equation are,

$$Ibat, Y = -3686.1x + 5980.2$$
$$Isrc, Y = 3905.2x - 1268.3$$
$$Iraw = 3986.3x - 1429.9$$

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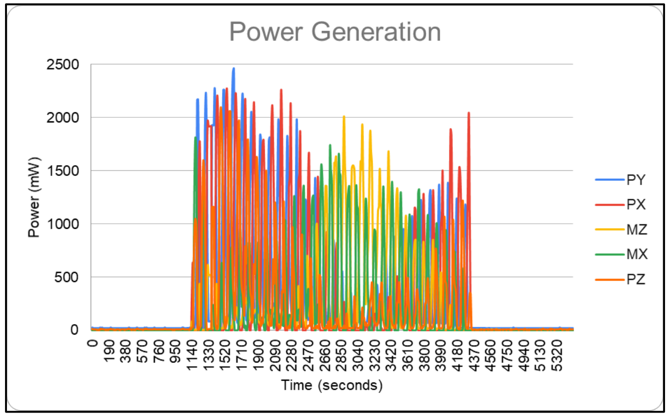
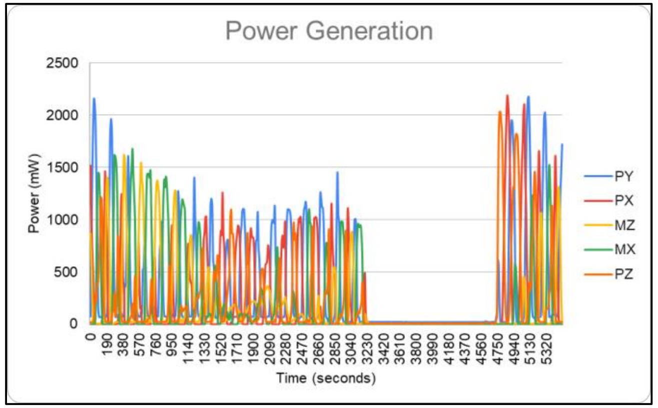
Power generation (Tsuru on-orbit data)

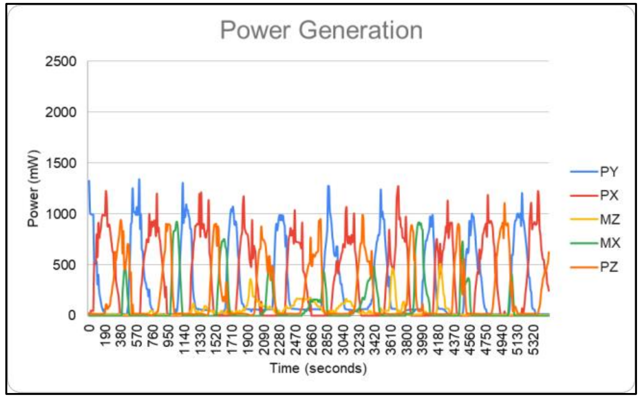
Date	June 1, 2021	July 9, 2021	July 17, 2021
Beta angle	0 deg	50 deg	70 deg
Power Generated	1,790 mWh	1,658 mWh	1,560 mWh

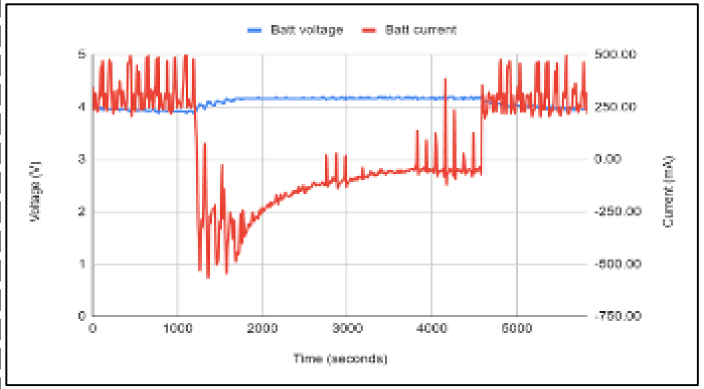
Conditions
- 5 panels working
- GPS is OFF
- Battery heater is OFF

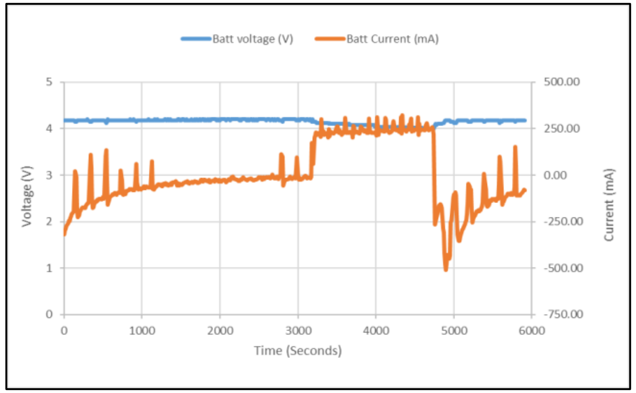
Observation
- Generated power is highest at 0 deg beta angle

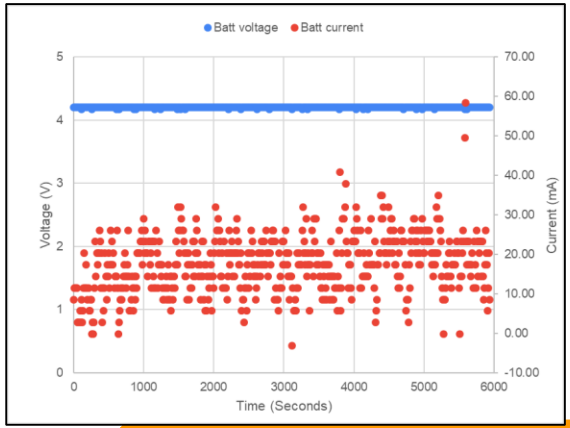








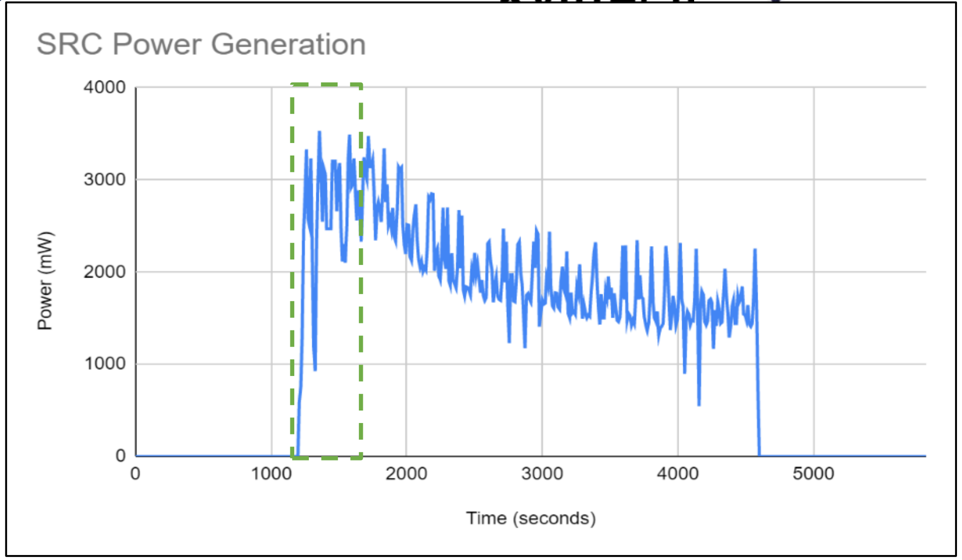


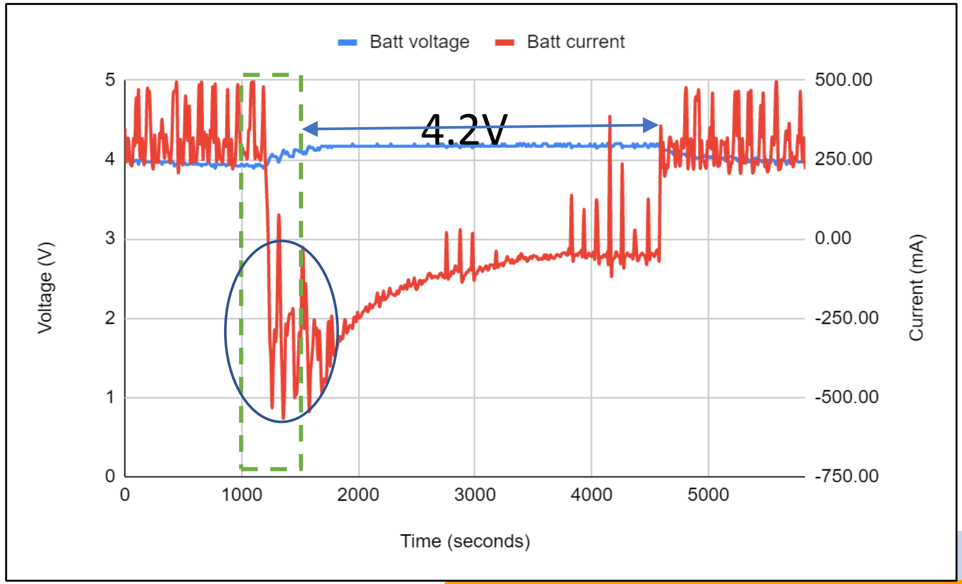


Available power to the load at 0 deg Beta angle (Tsuru on-orbit data)

- At 0 deg Beta angle, sunlit period is at 3,380 seconds (~56.3333 min.)
- It takes around 600 seconds for the battery to charge and reach 4.2 V when the satellite transitions from eclipse to sunlit.
- The average power generated during the 600 seconds period is

Parameters	**Unit**	**Beta angle = 0 deg. Eclipse time = 36 min.**		
Solar panels	-	5	4	3
Generated power	mW	2,670	2,136	1,602
Generated energy, **A**	mWh	2,507	2,005	1,504
Energy consumed by blocking diodes, **B**	mWh	240	192	144
BCR efficiency, **C**	%	80		
Energy loss at battery, **D**	mWh	210		
Available Energy to the load, **E** **E = [(A - B)*C] - D**	mWh	1,604	1,240	878





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BIRDS-4 EM satellite test (1/2)

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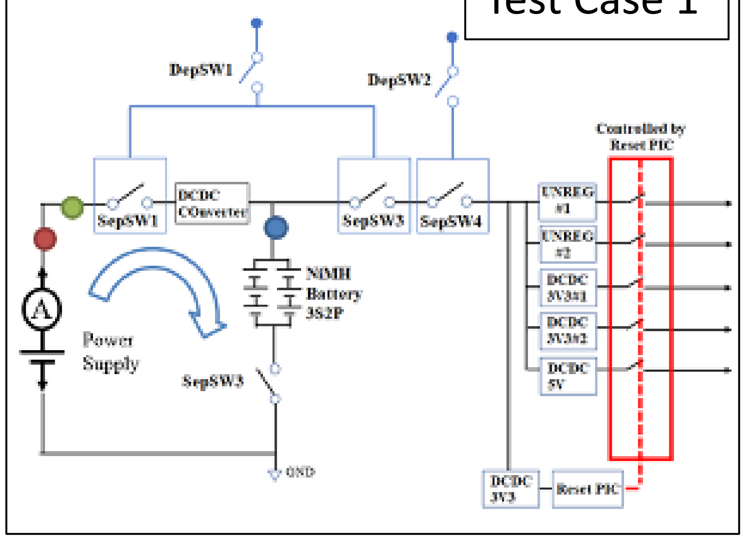
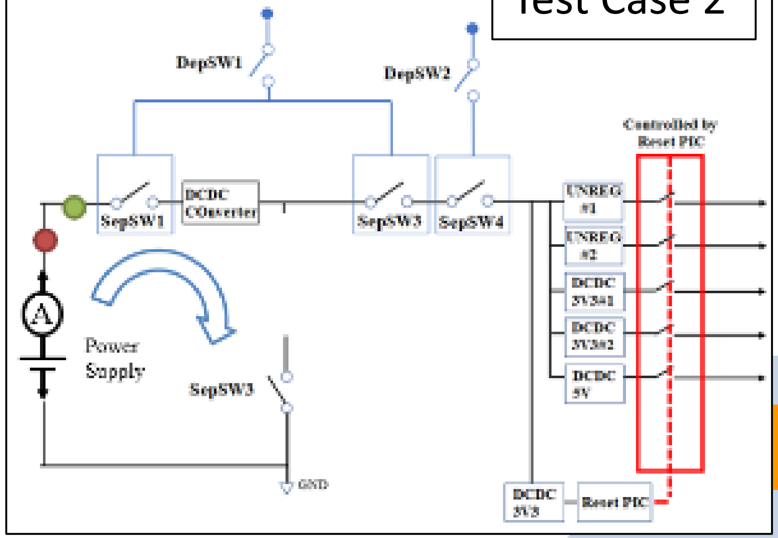
- EM satellite was used to verify the power consumption.
- Test cases
  1. With fully-charged battery
  2. Without battery
- Test setup:
  - antenna deployed
  - all internal boards are connected to the backplane
  - no solar panels
  - regulated power (4.2 V) supplied to the satellite through FAB J5 connector for case 1 and solar panel connector for case 2
  - GPS and battery heater are OFF

Test setup (Case 2)

Test Case 1



Test Case 2



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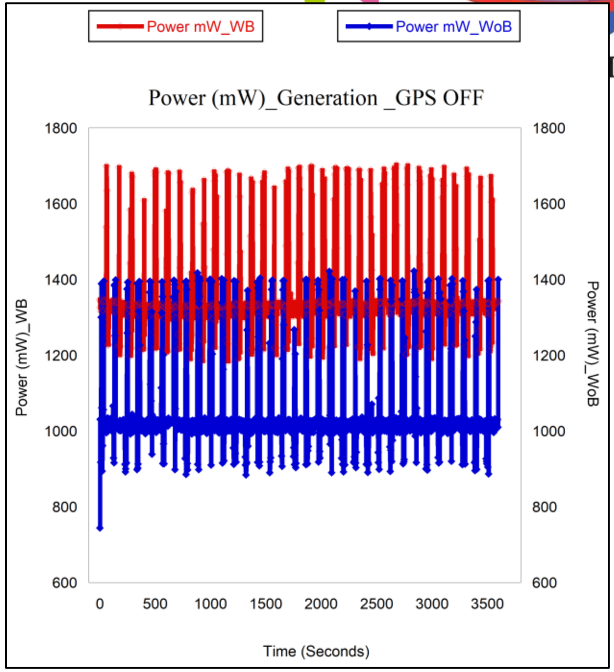
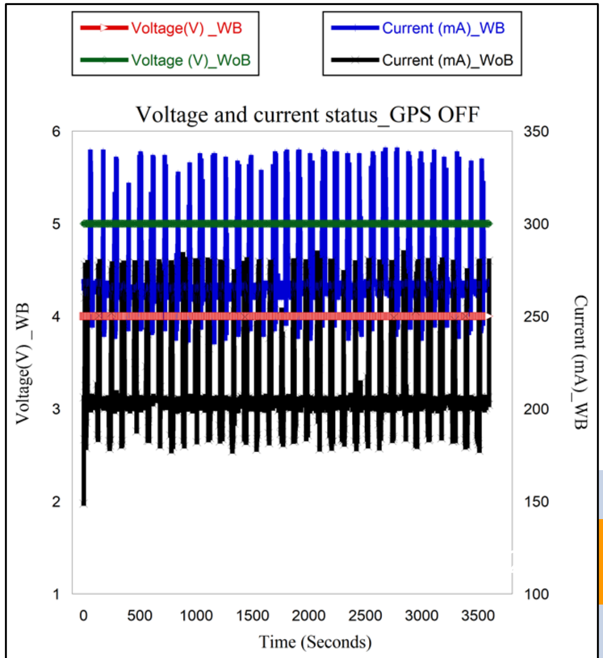
BIRDS-4 EM satellite test result (2/2)

Parameters	Unit	Power Source With Battery Connection (WB) Case-1	Power Source With - out Battery Connection (WoB) Case-2
Generated energy, **A**	mWh	2039	1578
Blocking diodes loss, **B**	mWh	360	
BCR efficiency, **C**	%	80	
Energy loss at battery, **D**	mWh	210	-
Available Energy to the load, **E** **E = [(A - B)*C] - D**	mWh	1133	974

NOTE: - Blocking diode loss (**B**), BCR efficiency (**C**), and energy loss in battery (**D**) are measured and same in page 7





Observation (On-orbit and Ground test)

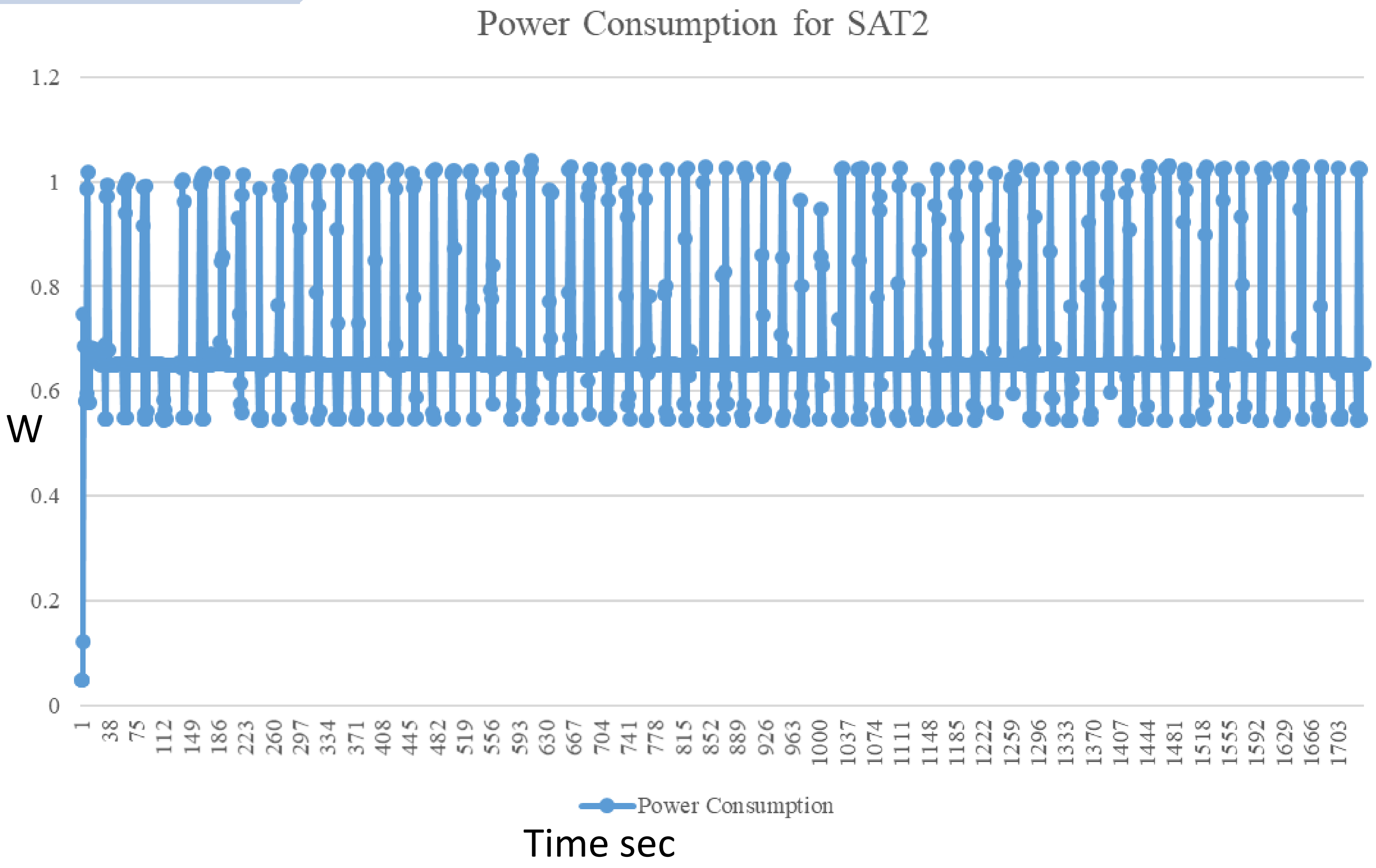
- For on-orbit at worst case, the available energy is 1604 mWh (at 5 solar panels)
- And, according to ground test results the available energy 1133 mWh

The results of the on-orbit and ground tests are not exactly equivalent because,

- ✓ During test battery was fully charged and receiving in constant power from power source

Nominal power consumption

- High Sampling Data from BIRDS-5 FM satellite (30 Minutes) Nominal power consumption = 650mW.
- Hence total energy consumption = 700 mW x 1.5 h (Orbital period) = 1050 mWh.



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Source:BIRDS-5

Summary and Conclusion

- Focus on power budget reliability based on flight data rather than simulation. The estimated power generation in one orbit is *2500mWh* in one orbit and the available power to the load is *1600mWh* for the case of 5 solar panels working

- Estimate the Power Generation from the satellite in the worst-case (Low Beta)>>please follow this rule.

- The nominal power consumption of the satellite per orbit should be around 1000mWh or less, so that the satellite can continue to function even if one solar panel fails

- Due to the general flight experiences of the BIRDS-3 and BIRS-4 satellites, there is no need to use a battery heater on the satellite.(we can save the energy).

- Power generation can vary depending on the satellite's TLE (high or low beta angle), initial orientation, rotation speed, and other parameters.

EPS functionality tests

- ❑ Safety review

Inhibit test (overcharge, over discharge and external short)

>> Deployment switch screening and Inhibit test

>>Battery screening and cell matching after doing environmental test(Vaccuum, vibration)

>>Battery Lot sampling test at high temperature

Functional test

- ❑ MPPC and BCR efficiency test
- ❑ Diode(reverse) test
- ❑ Battery recover test
- ❑ Housekeeping data analysis (sensor calibration)
- ❑ Solar cells attachment and its characterization
- ❑ Each component power consumption (nominal and rush current) test
- ❑ Over current protection and sensitivity test
- ❑ FAB PIC and RESET PIC communication with Main PIC and COM PIC

Acknowledgements

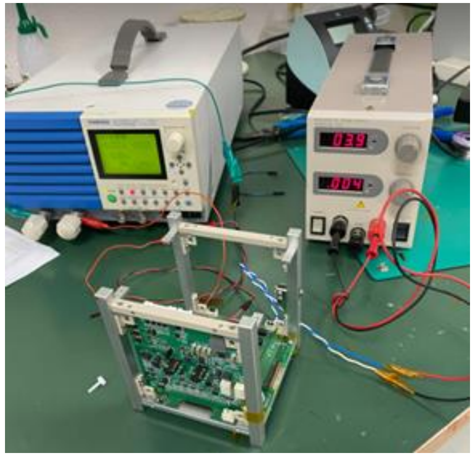
- Prof. Mengu Cho
- BIRDS members

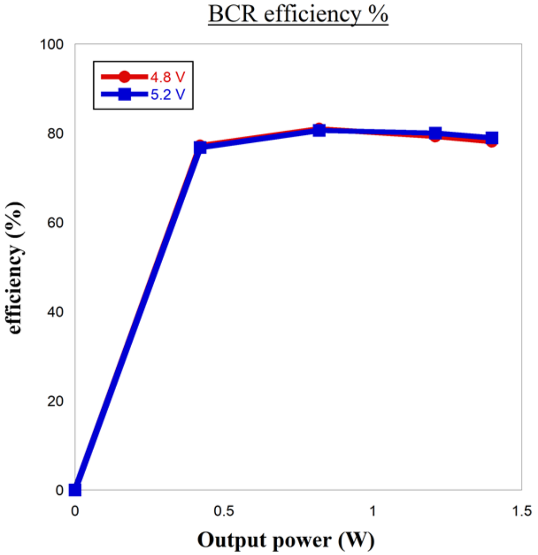
Test and Data Analysis :Hari, IZ , Adolfo ,Marloun

Thank you

- Appendix

Blocking Diode and BCR Characterization

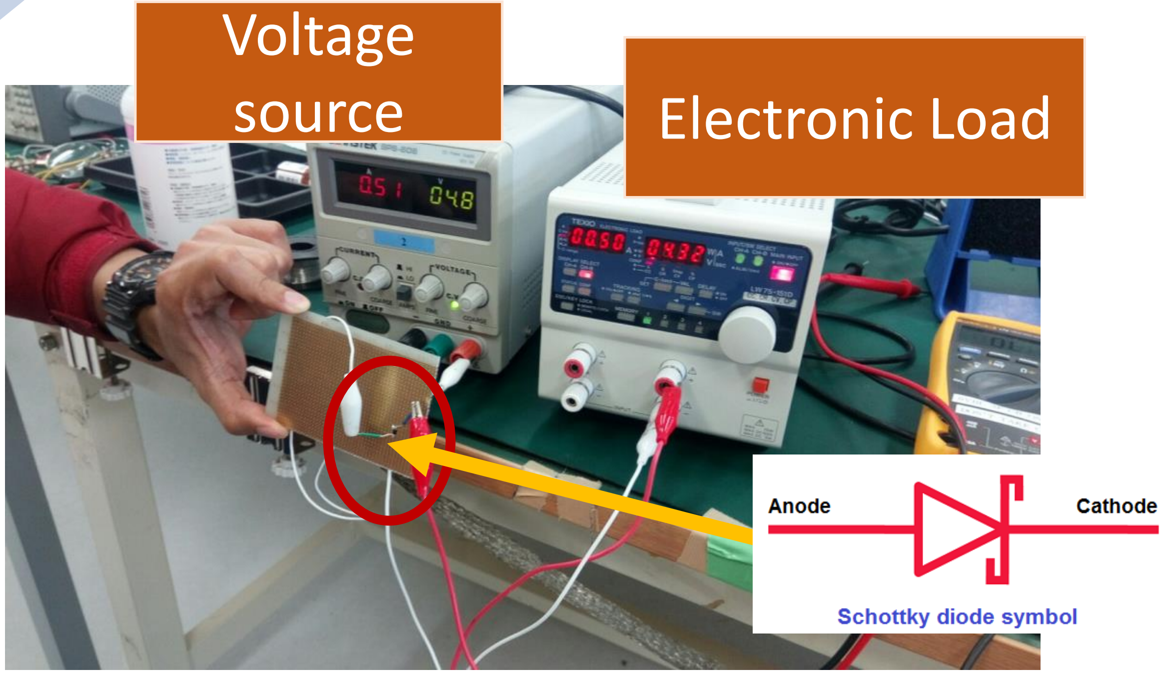




- Efficiency % = (Output power (w)/ Input power (W))X100%

Test condition,

1. At 4.80 V Input constant voltage
2. At 5.20 Input voltage constant voltage



Test appearance

- ➢ Voltage source =4.8 V
- ➢ Consume current by electronic load by= 0.5 A
- ➢ Voltage drop=0.48 V
- ➢ Power loss= 240mW

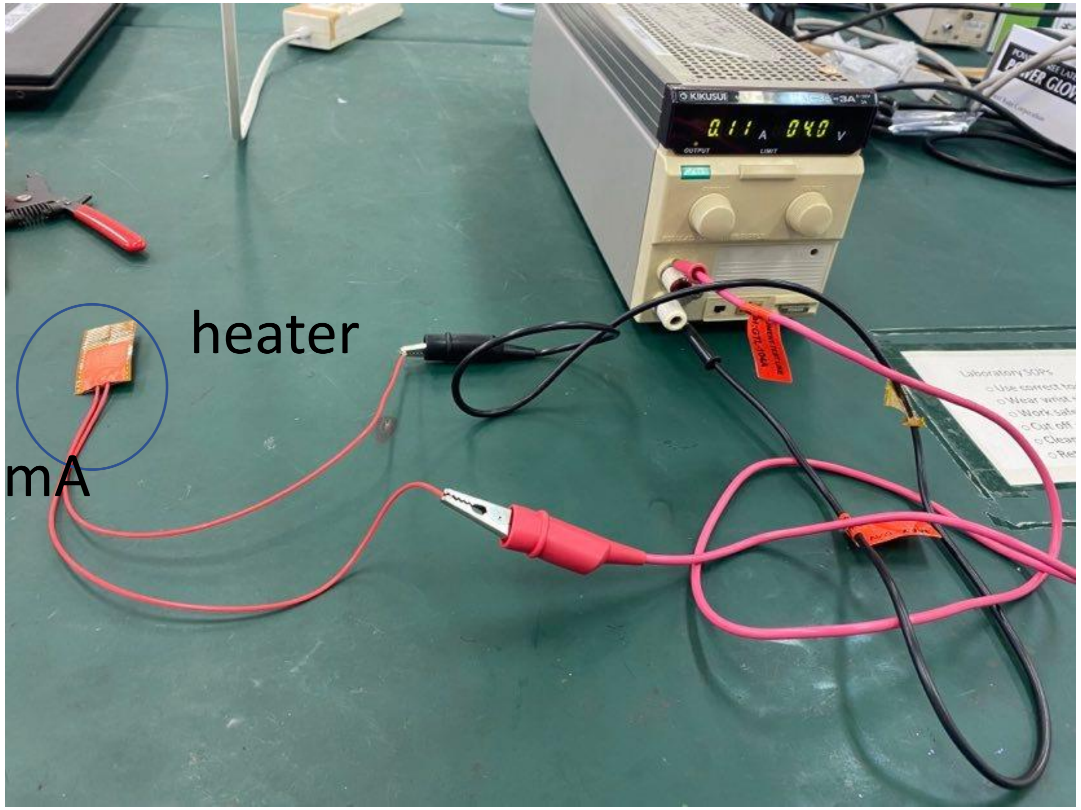
Battery heater calculation

Supply voltage = 4.0 V to 4.2 V

Heater resistance= 40 Ω

$$I = V/R$$

Current consuming = 110 mA to 130 mA

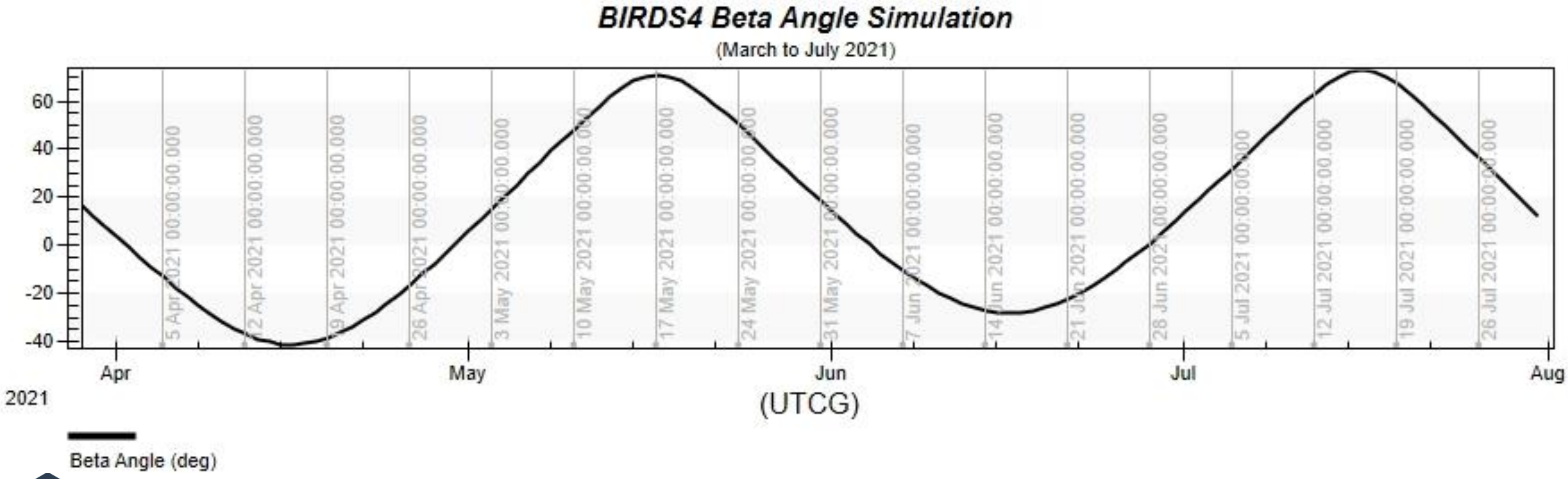


Beta Angle Prediction (March to July 2021)

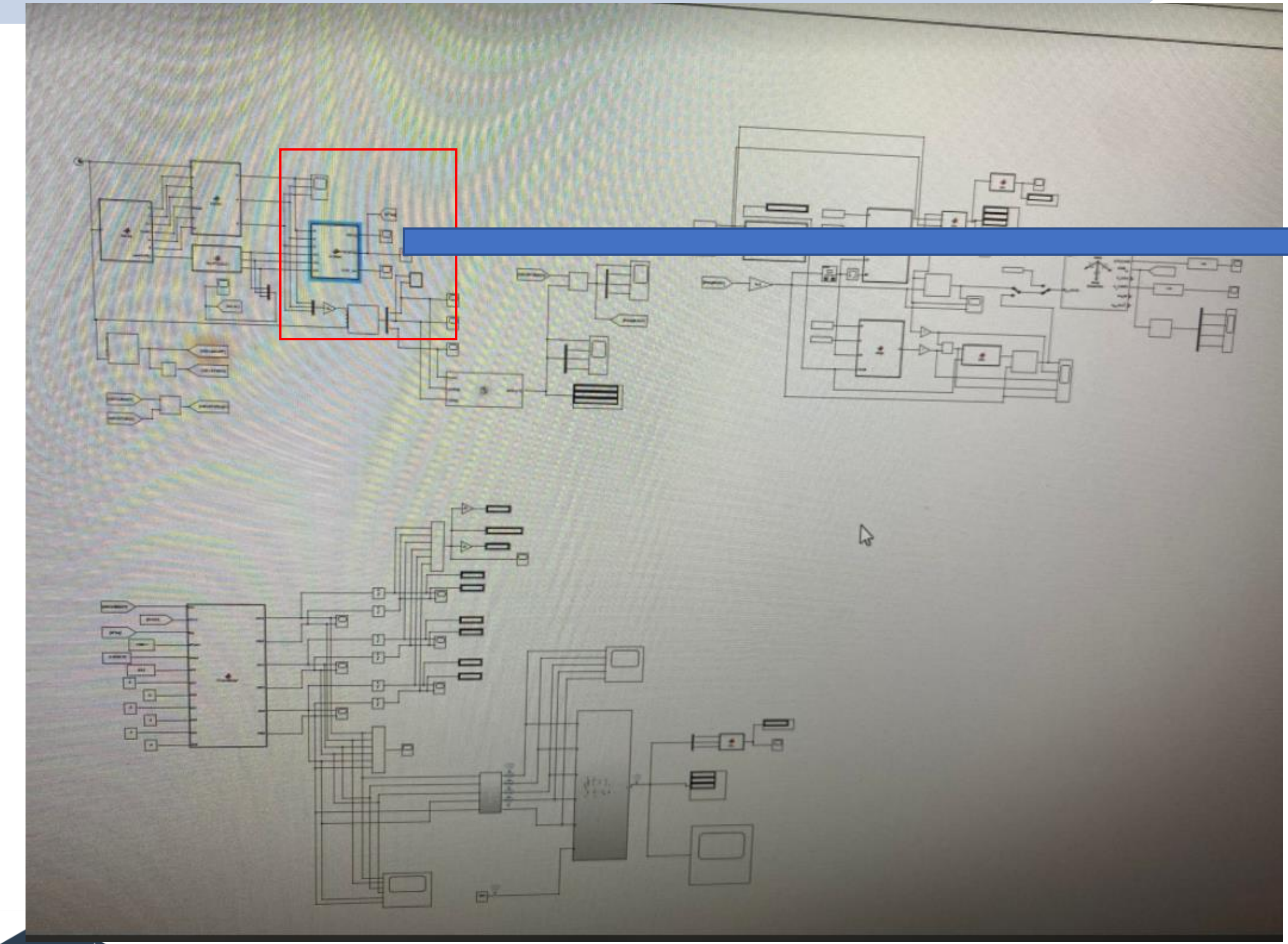
Parameters:

Elevation = 416.86 km

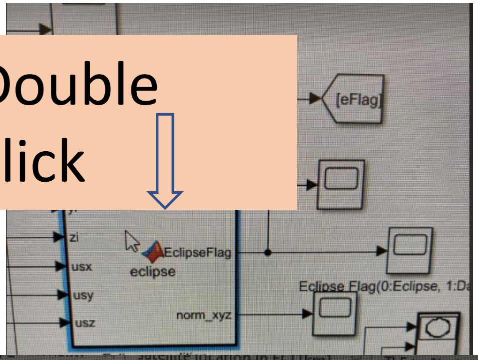
Inclination = 51.6444 deg

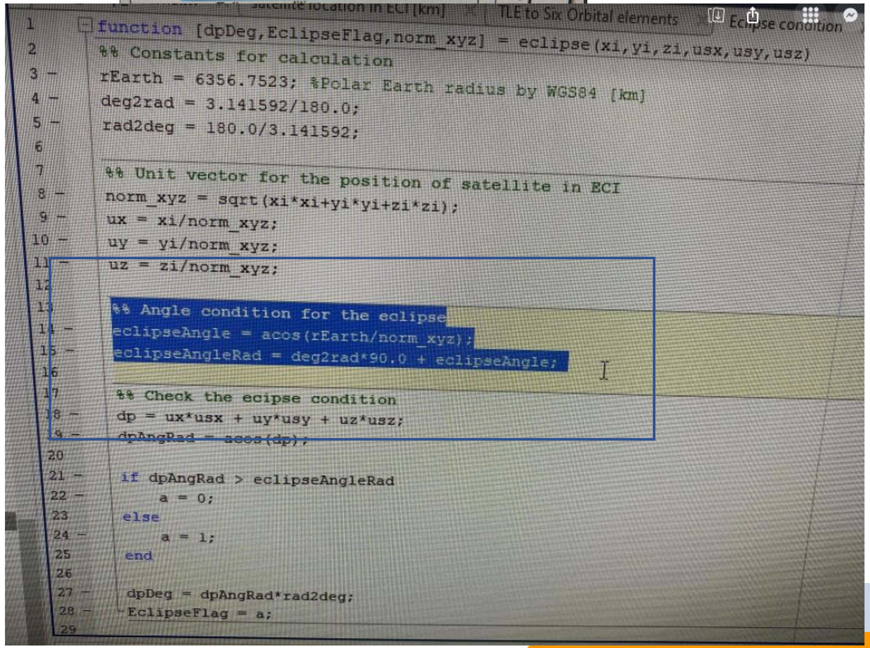


Simulation task



Double click



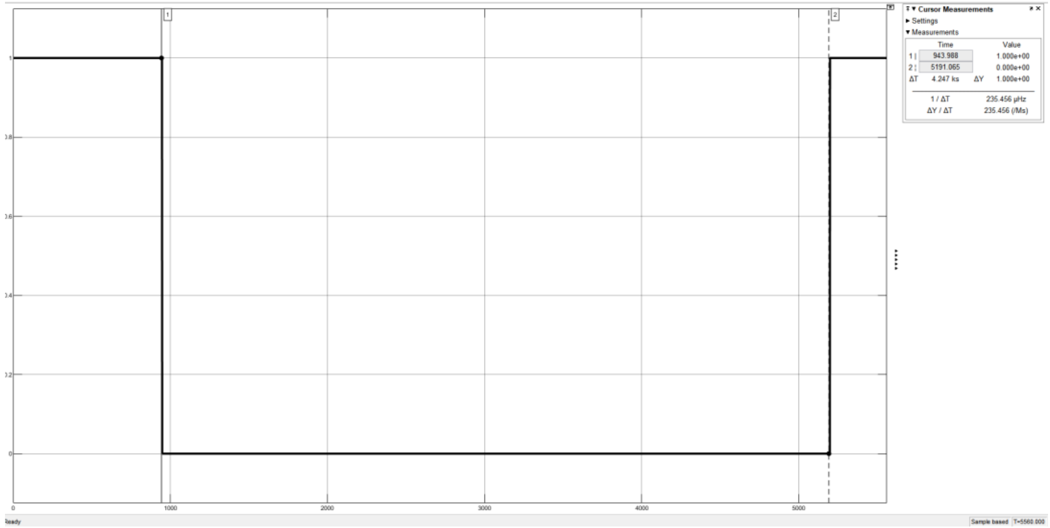


Power generation simulation using MATLAB

```
%% Angle condition for the eclipse
eclipseAngle = acos(rEarth/norm_xyz);
eclipseAngleRad = deg2rad*30.0 + eclipseAngle;
```

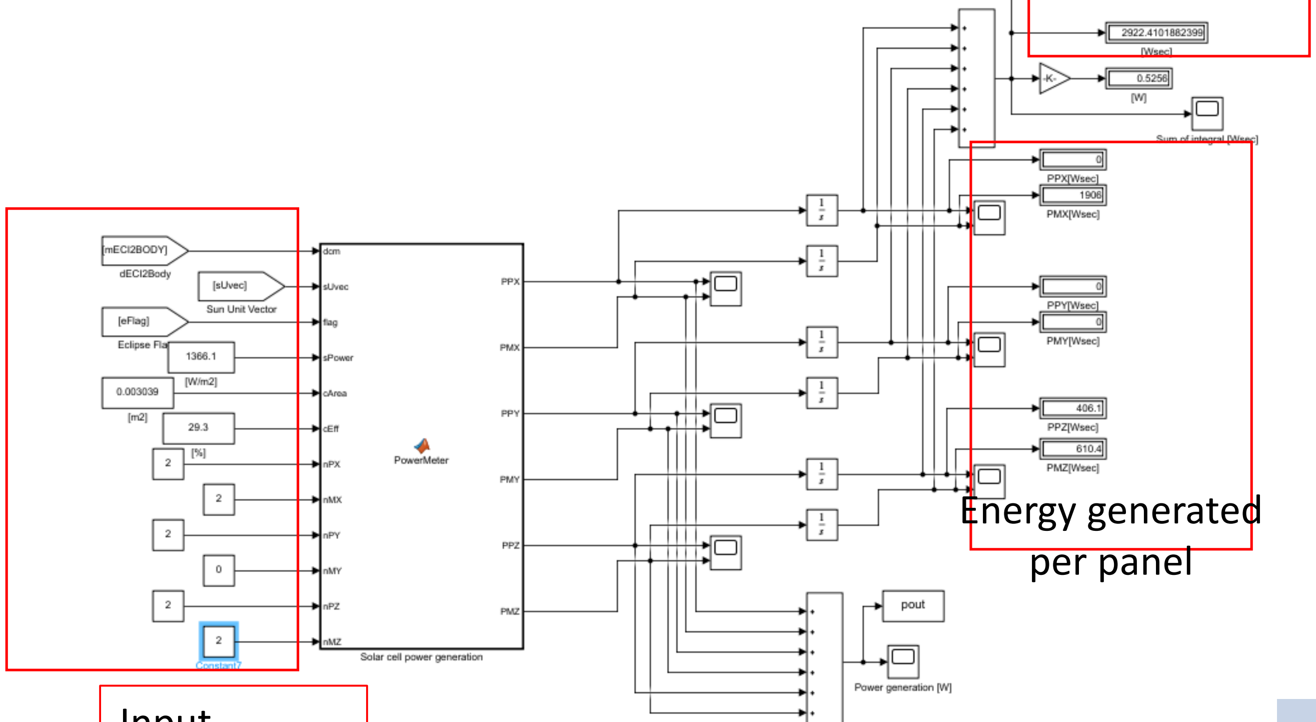
With 5 solar panels working

(+X, -X, +Y, +Z, -Z)



Eclipse time is 72 min

Total energy and power generated



Energy generated per panel

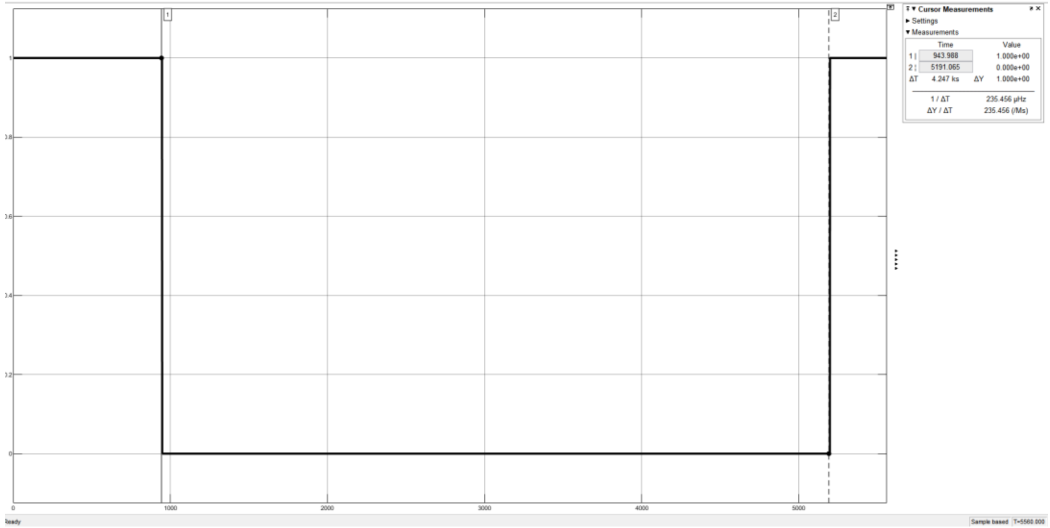
Input parameters to the simulation

Power generation simulation using MATLAB

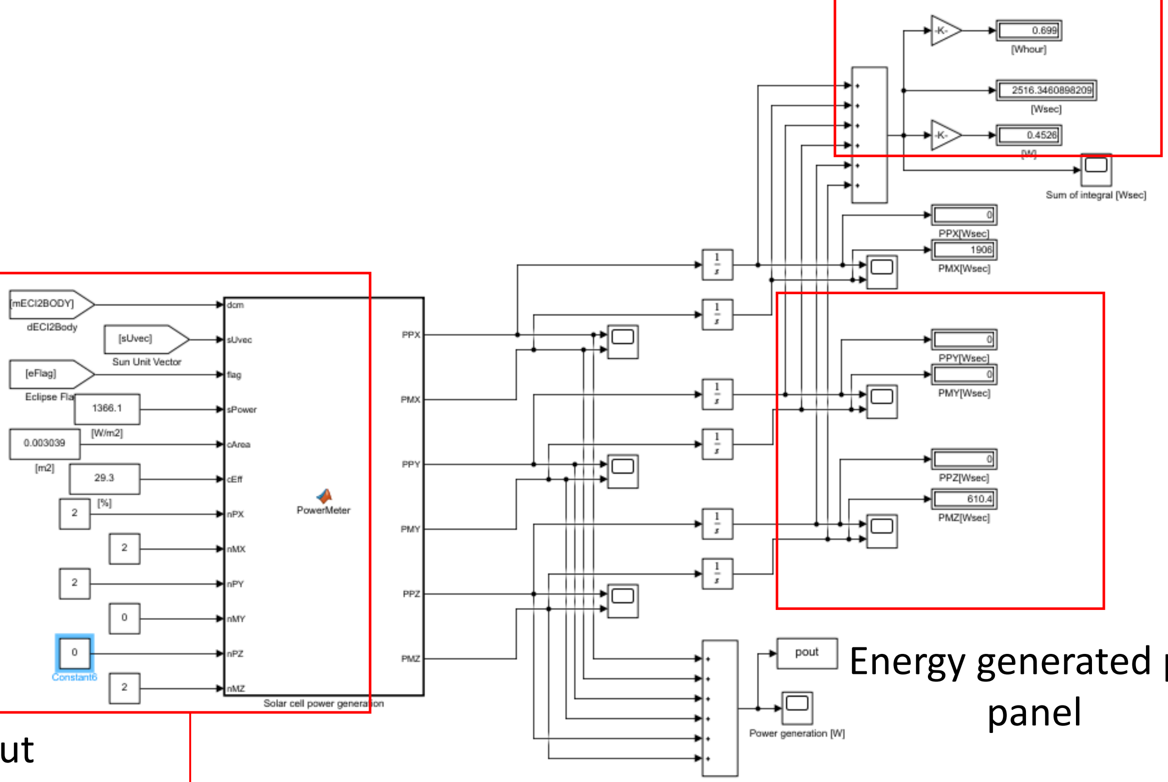
```
%% Angle condition for the eclipse
eclipseAngle = acos(rEarth/norm_xyz);
eclipseAngleRad = deg2rad*30.0 + eclipseAngle;
```

With 4 solar panels working

(+X, -X, +Y, -Z)



Total energy and power generated



Energy generated per panel

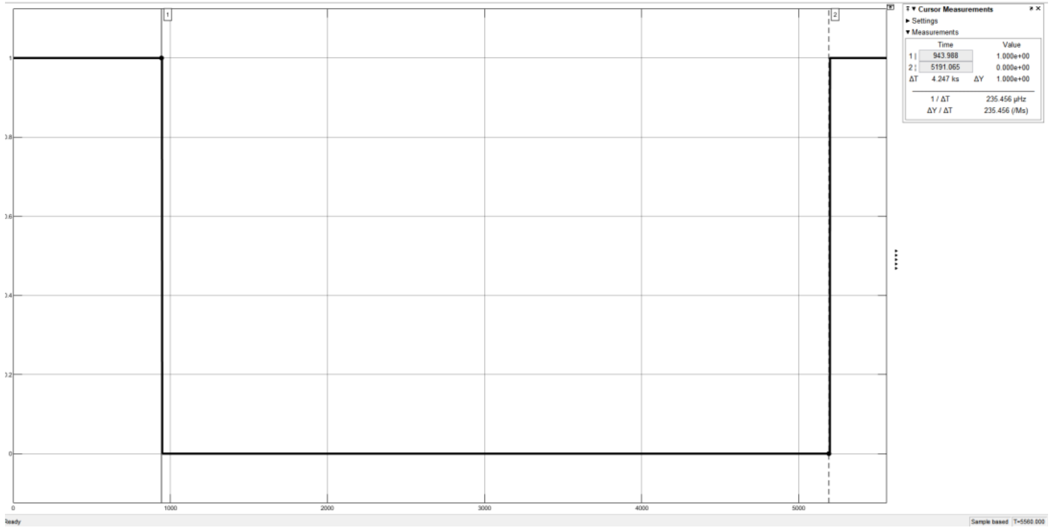
Input parameters to the simulation

Power generation simulation using MATLAB

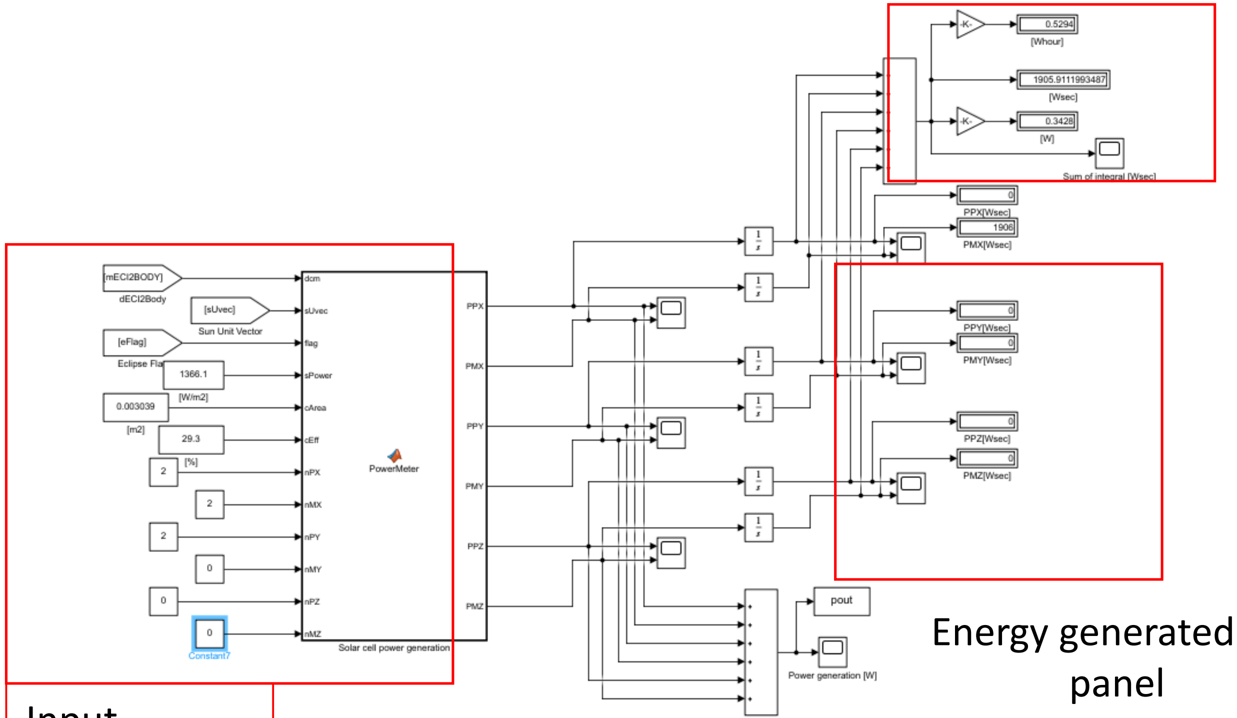
```
%% Angle condition for the eclipse
eclipseAngle = acos(rEarth/norm_xyz);
eclipseAngleRad = deg2rad*30.0 + eclipseAngle;
```

With 3 solar panels working

(+X, -X, +Y,)



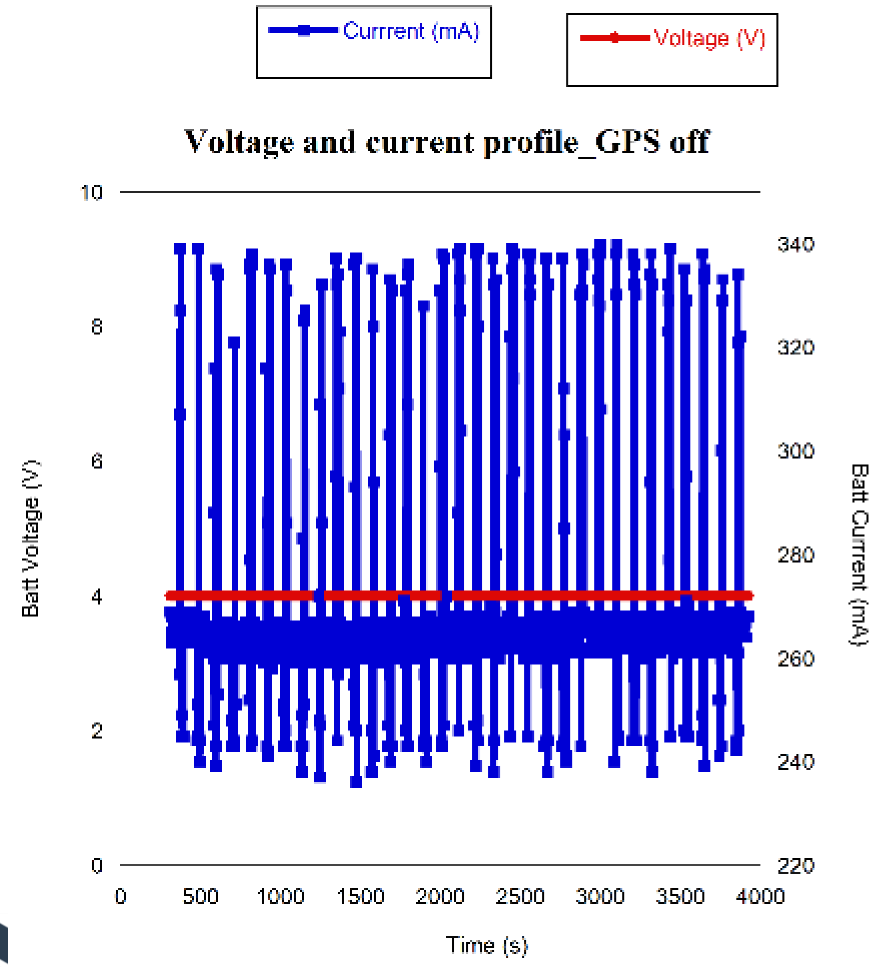
Total energy and power generated

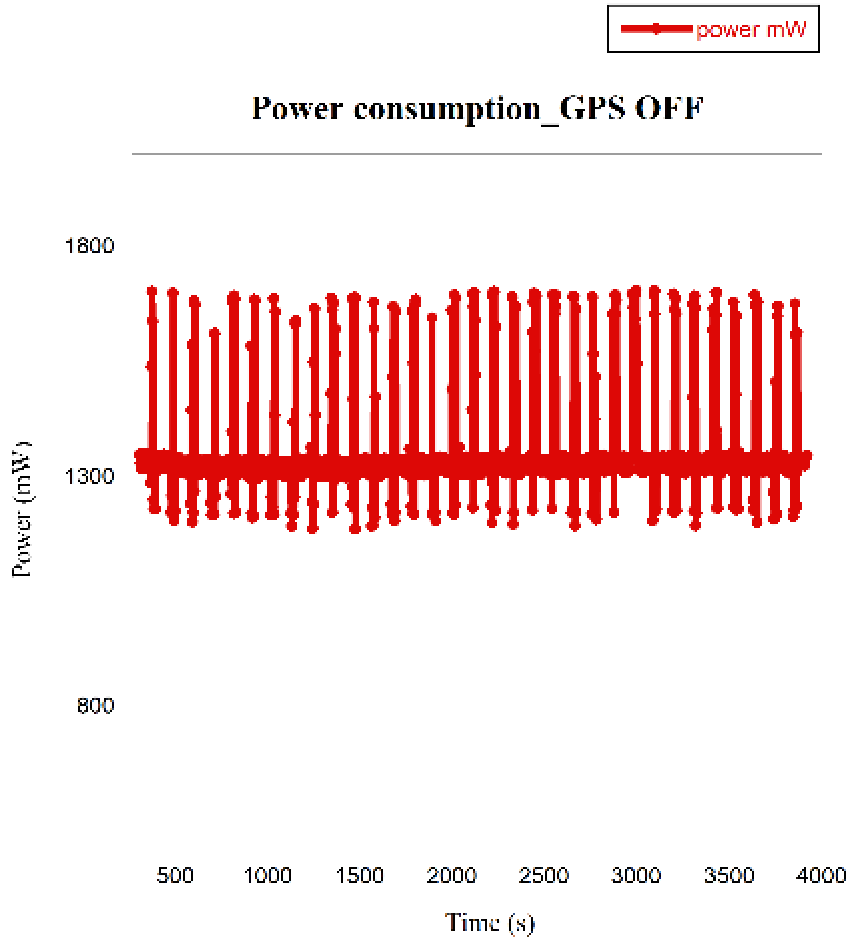


Input parameters to the simulation

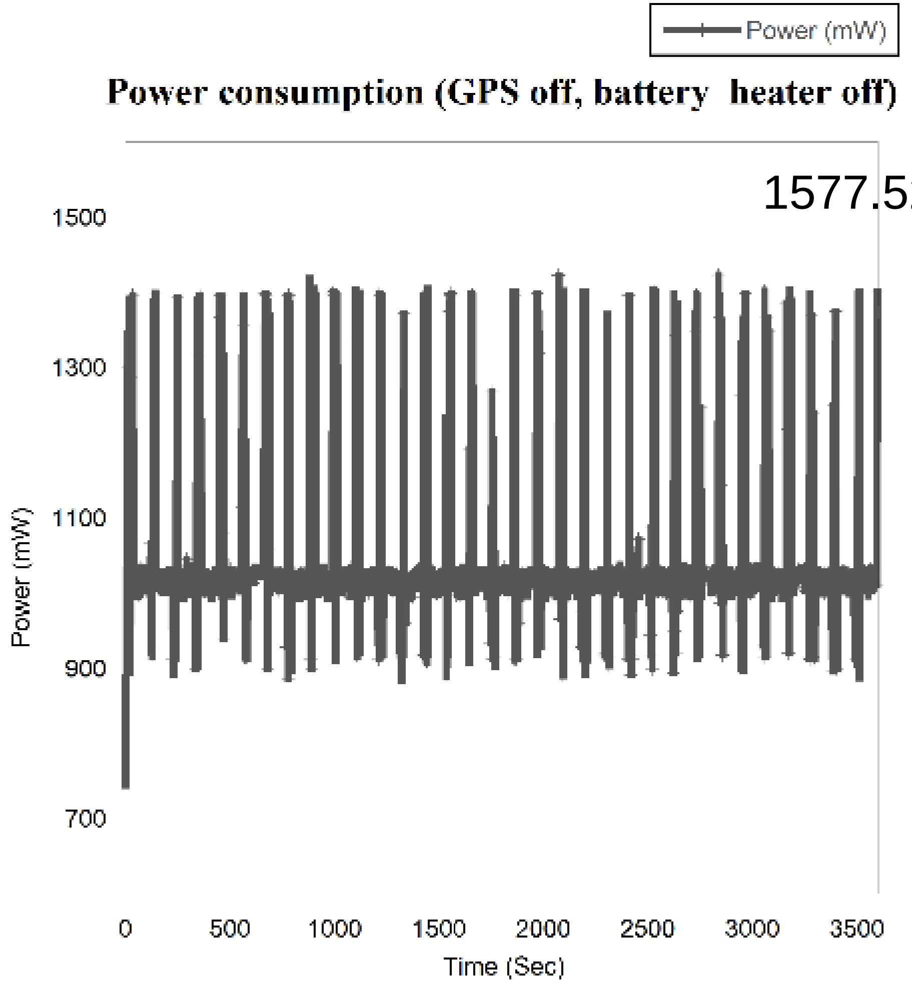
Energy generated per panel

Test with battery connected (GPS OFF, heater OFF)

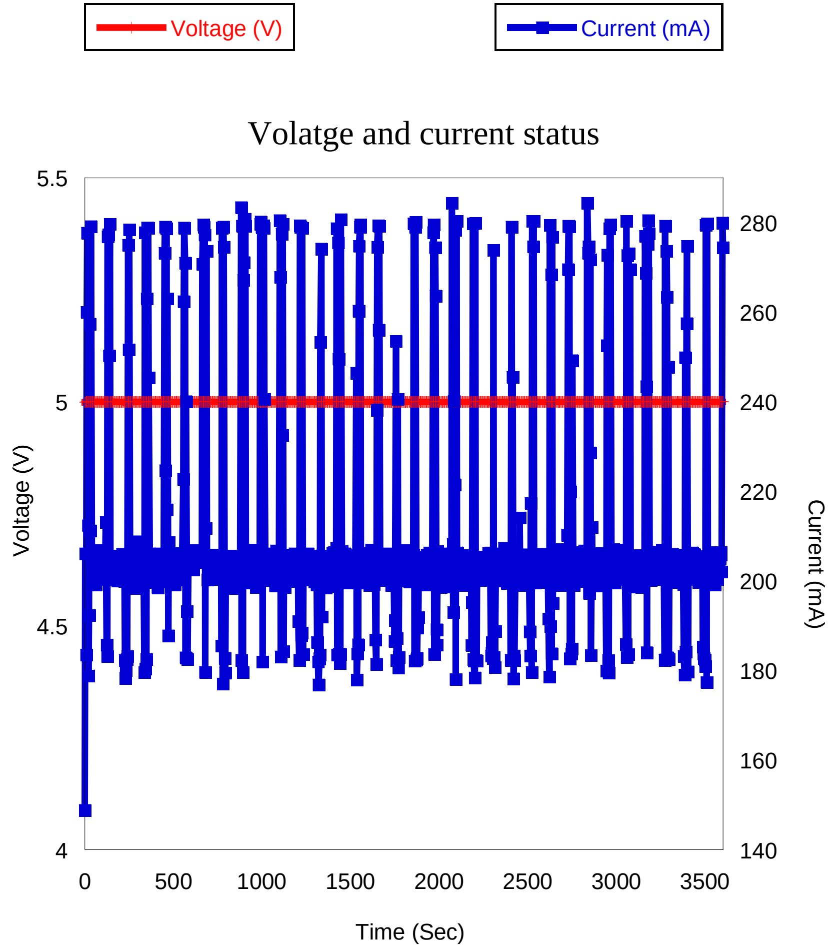




Test without battery connected (GPS OFF, heater OFF)



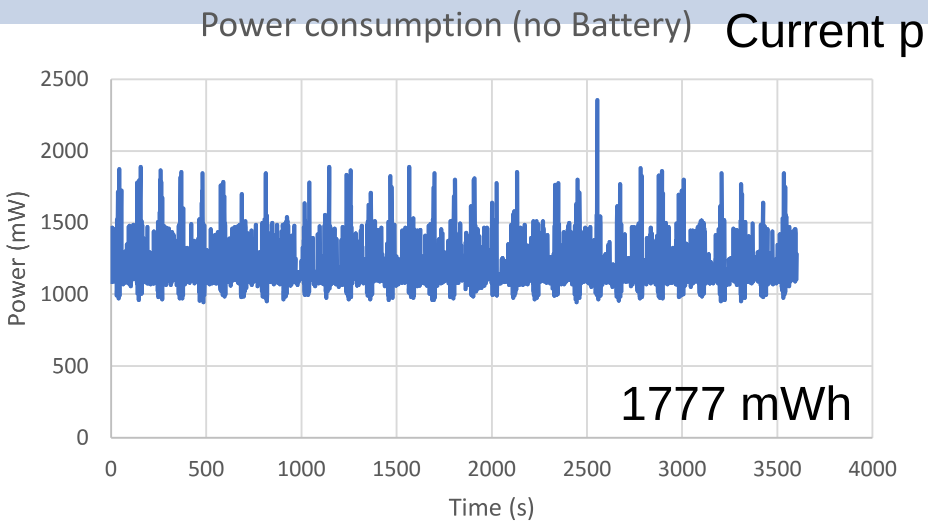
1577.52 mWh in one orbit

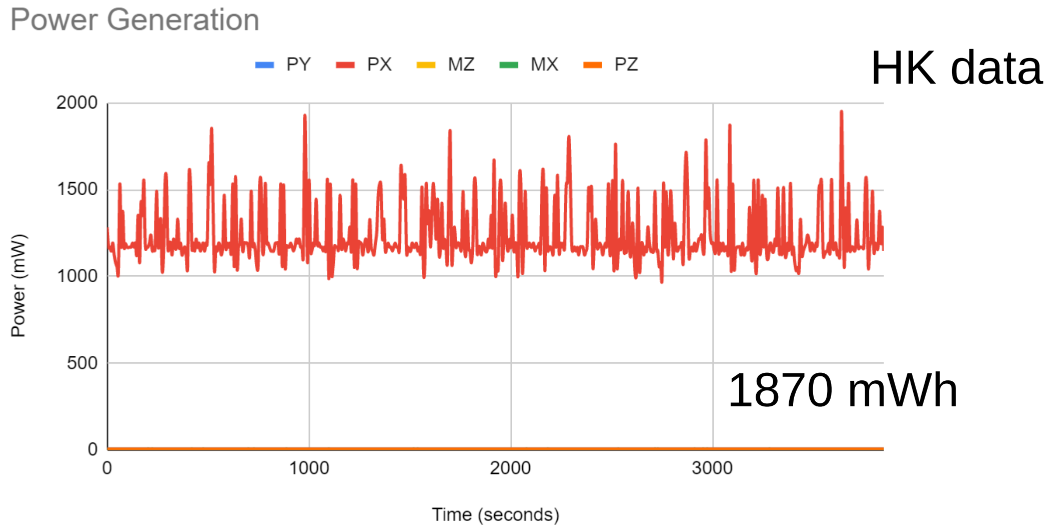


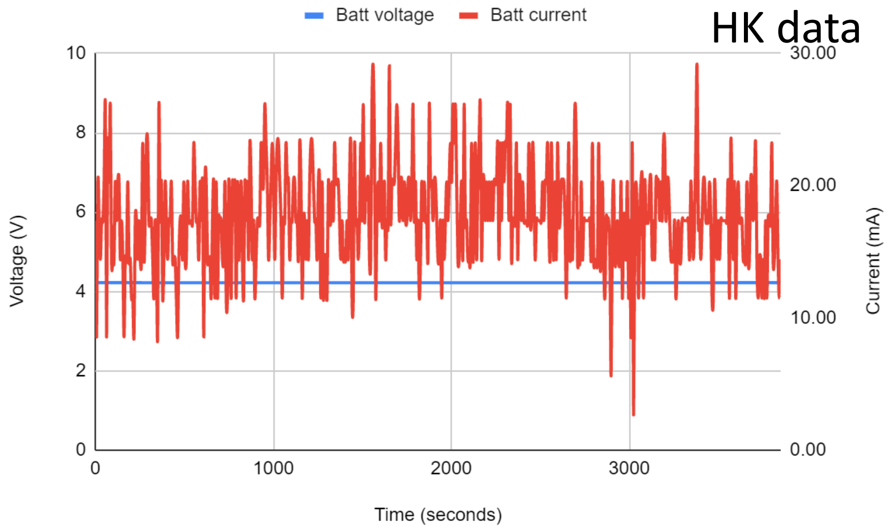
BIRDS-4
JOINT GLOBAL MULTI-NATION BIRDS SATELLITE PROJECT

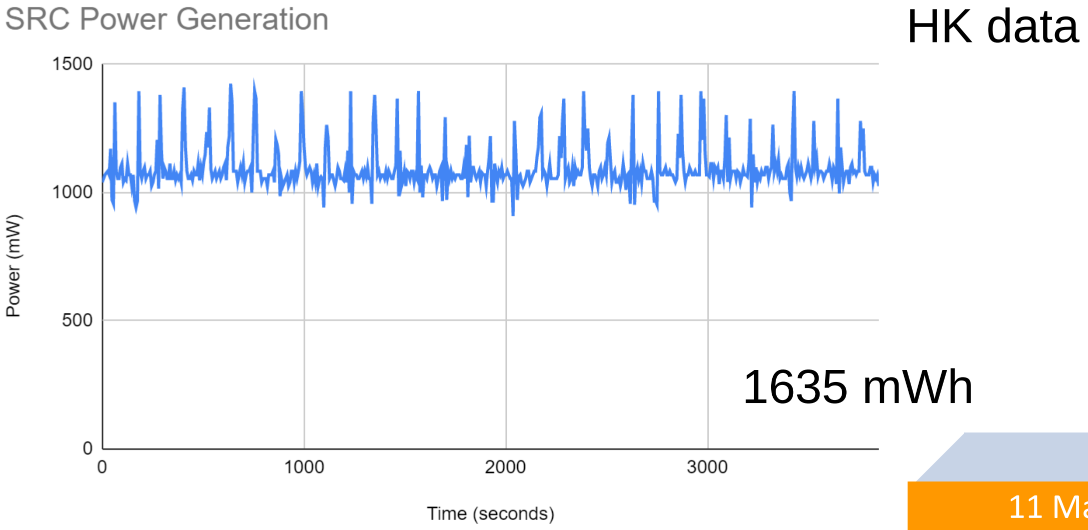
Test without battery connected (GPS ON, heater OFF)

Kyutech
Kyushu Institute of Technology
La SEINE

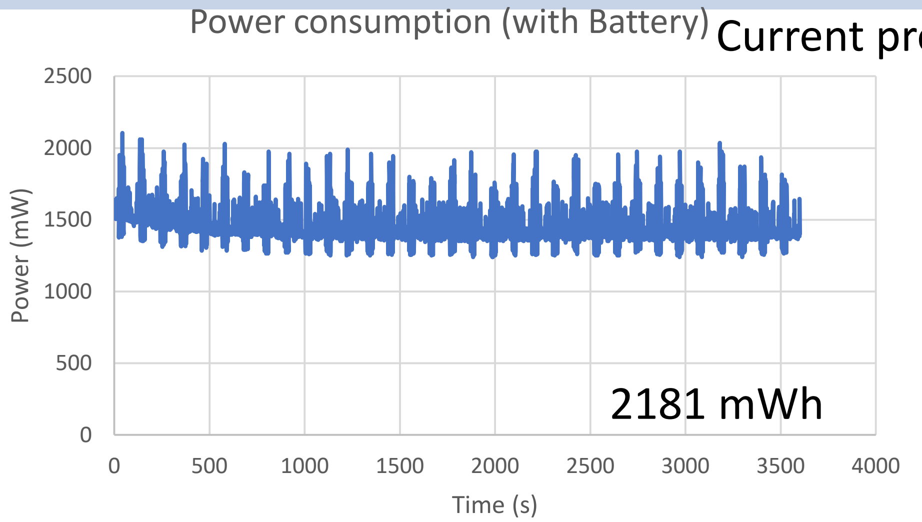






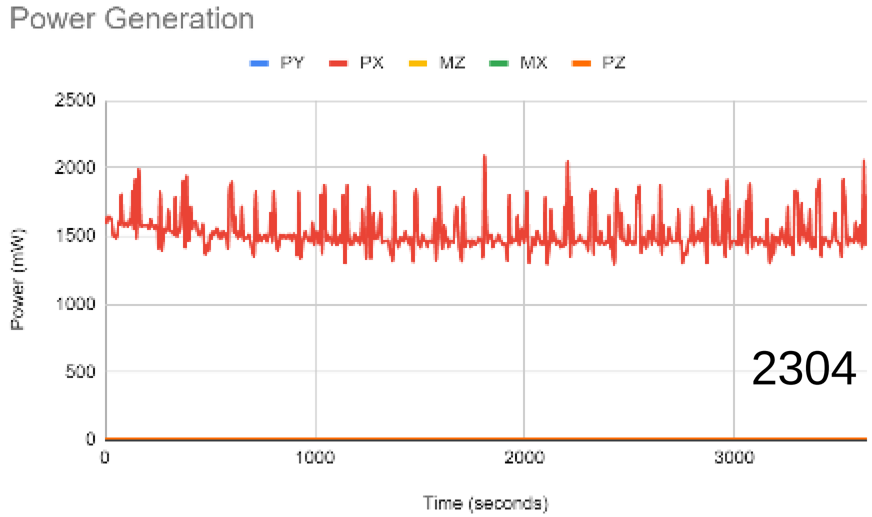


Test with battery connected (GPS ON, heater OFF)



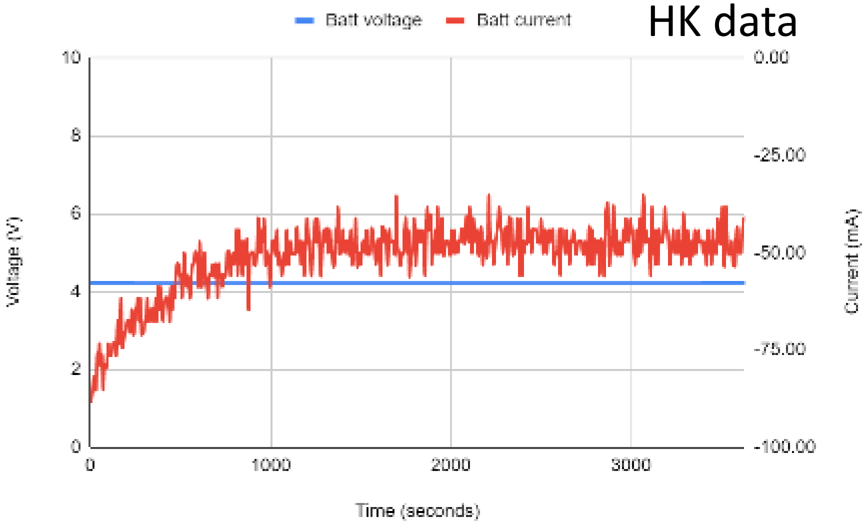
Current probe

2181 mWh

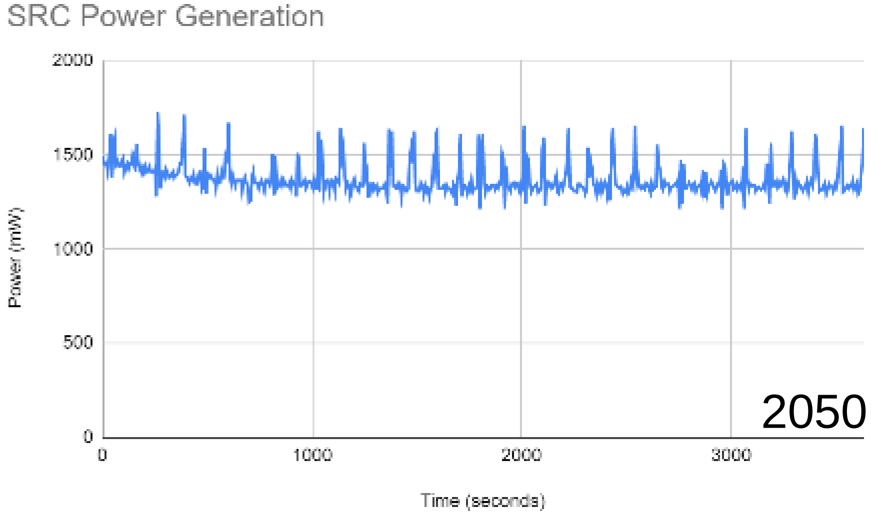


HK data

2304 mWh



HK data

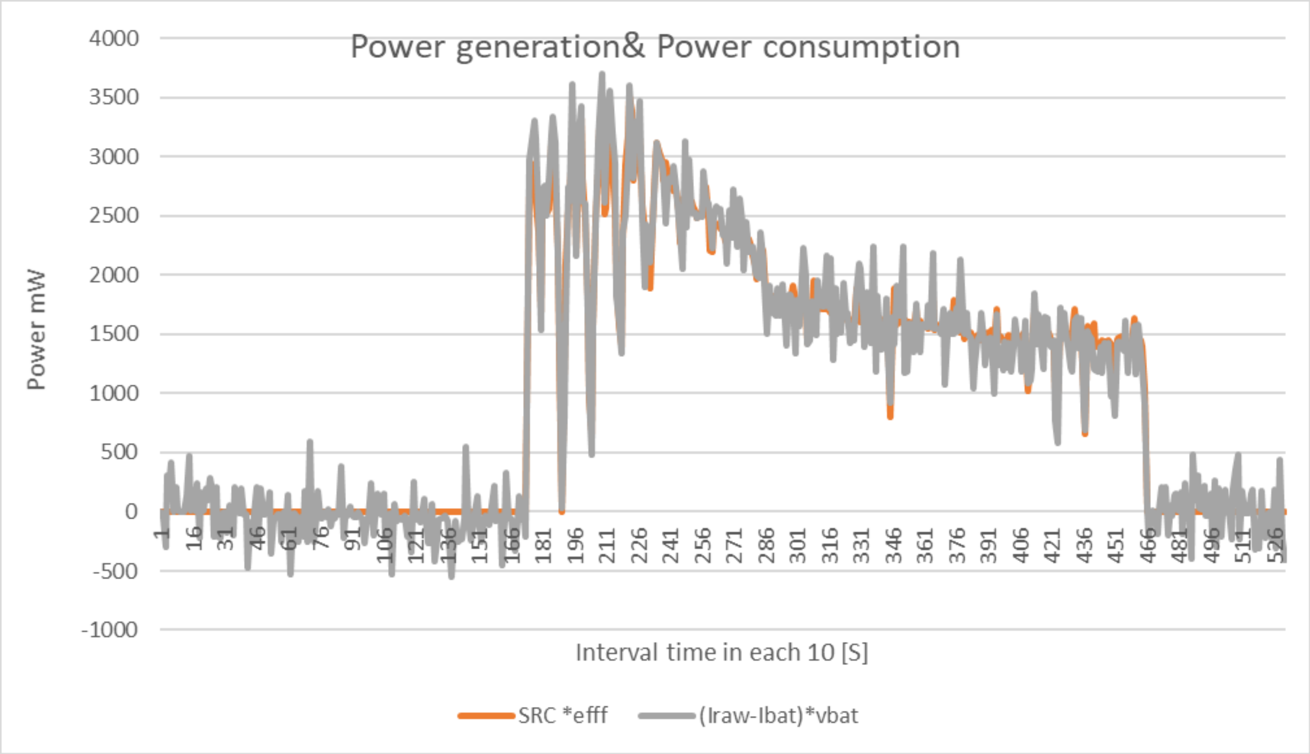


HK data

2050 mWh

Isrc, Iraw & Ibat in the same orbit.

calculate the total power generated using the newly calibrated



SRC*efficiency = (Iraw-Ibat)*Vbat