# Power Budget Analysis for 1U satellite

BIRDS-EPS
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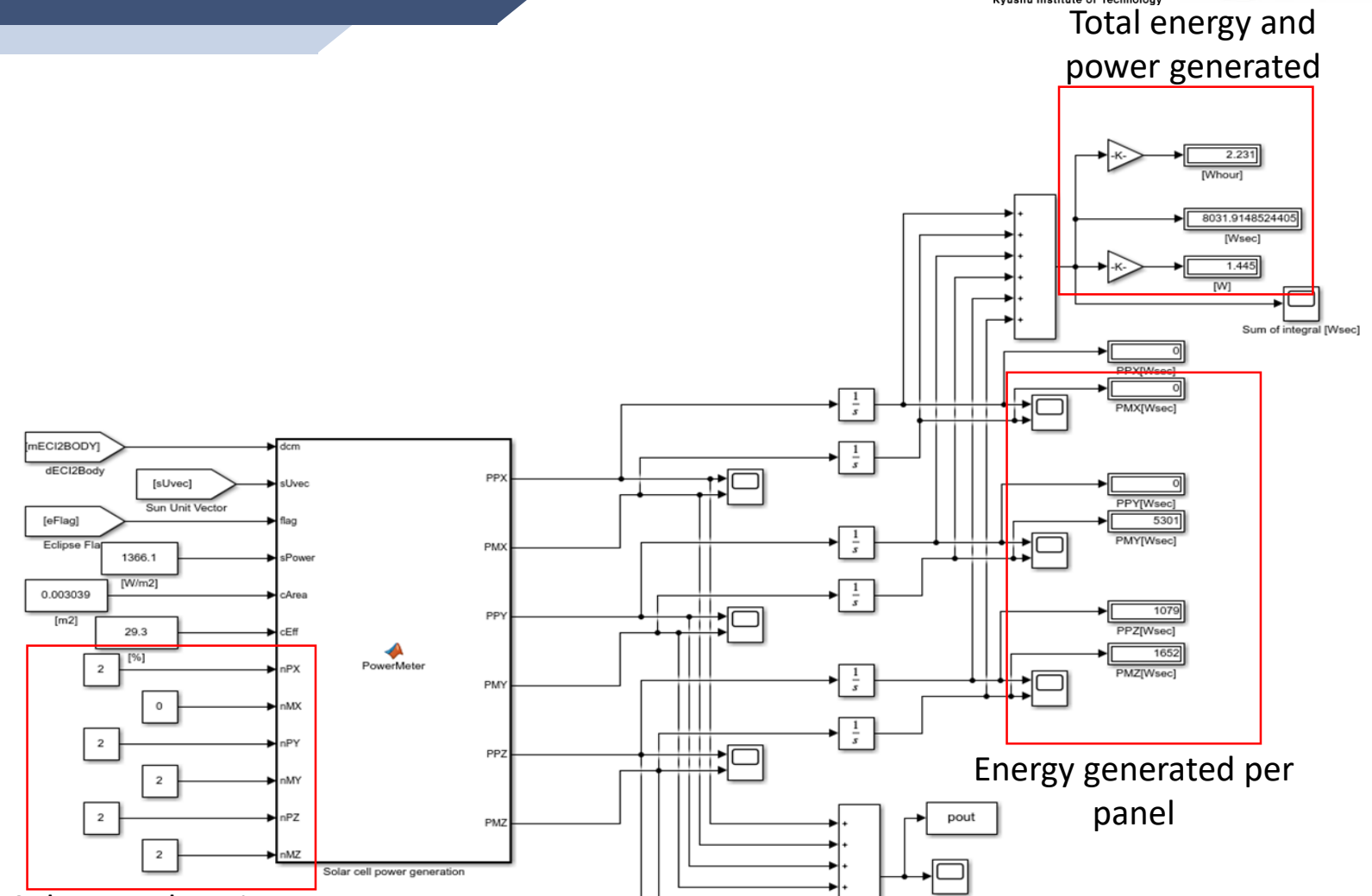
# Power generation simulation using MATLAB (1/2)

- 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.

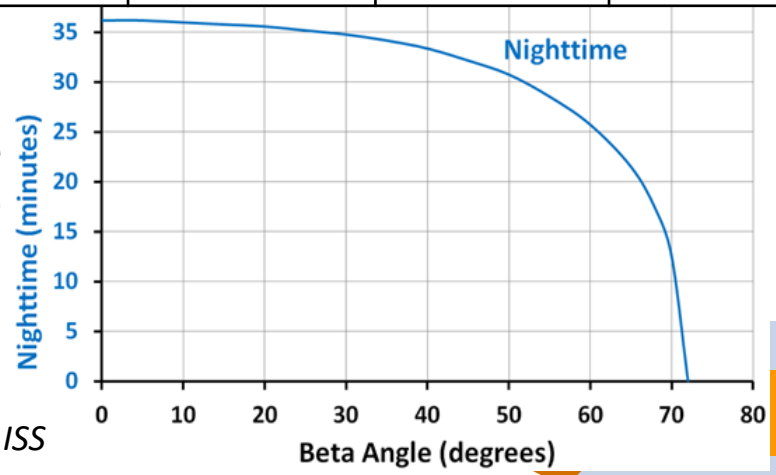


# Power generation simulation using MATLAB (2/2)

| 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. Details can be found in the Appendix.



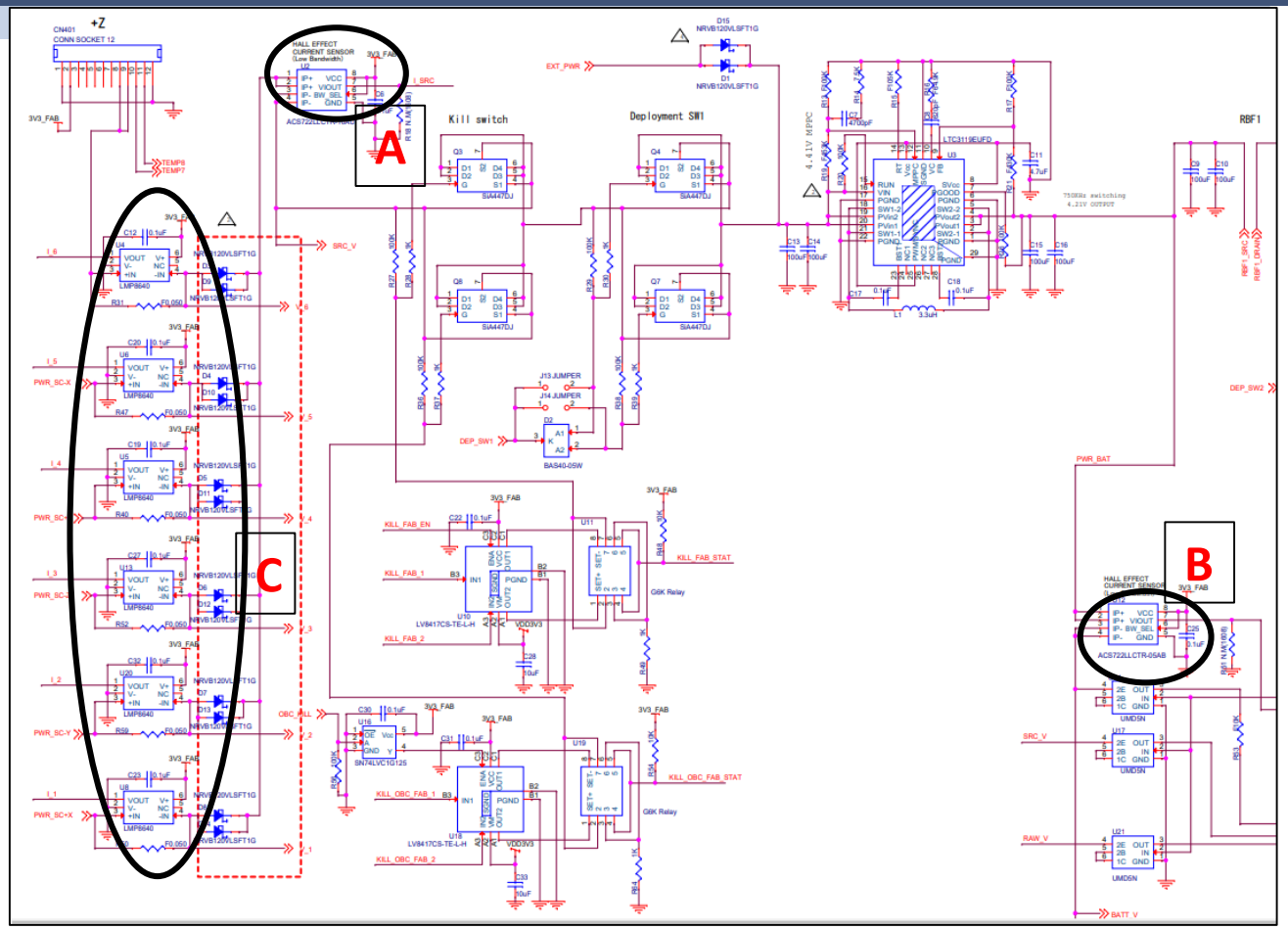

*Reference: ISS*

# BIRDS-4 Power Consumption (Measured)

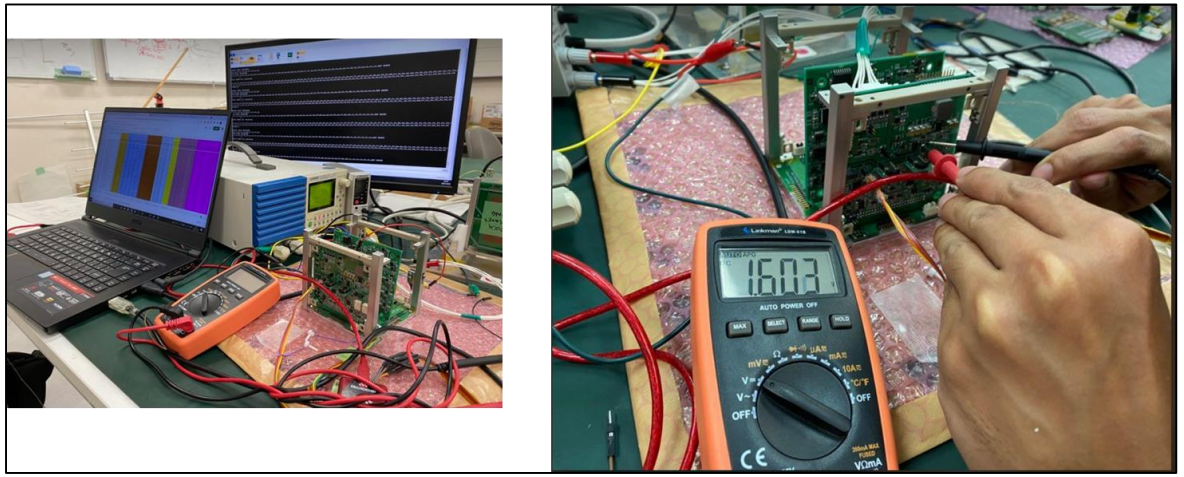
- Power consumption per subsystem and per payload were measured
- The duration were subsystem and payload were ON is based on 90-minute orbit
- **At nominal mode, BIRDS-4 satellites energy consumption is at 1,438 mWh**

| 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 (Detumbling Modde) | 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 | |
| Nominal Mode | ON | ON | ON | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | ON | OFF | OFF | OFF | ON | ON | 1438 |

# Current sensors calibration




BIRDS-4 FAB schematic



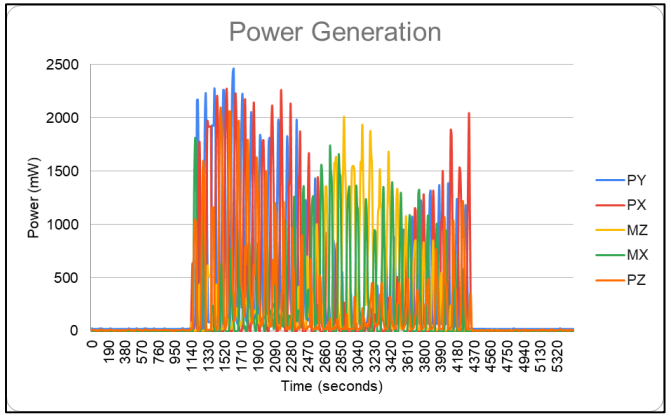
- Measurements were taken on the source current sensor (**A**), battery current sensor (**B**), and individual solar panel source current sensors (**C**) with under different temperature conditions: +25 degC, +60 degC, -10 degC
- Based on the measurements, each sensor's HK data formula were updated.

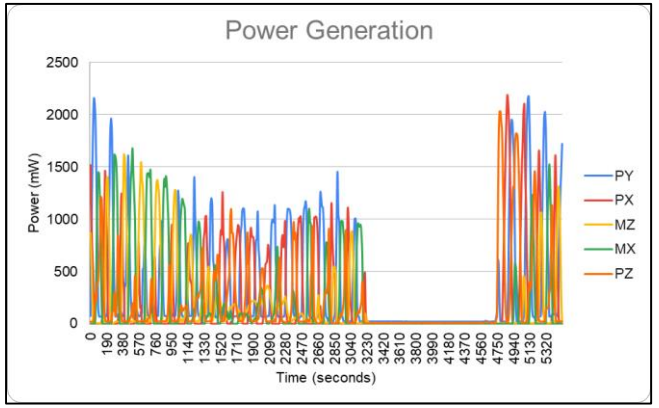
# Power generation (Tsuru on-orbit data)

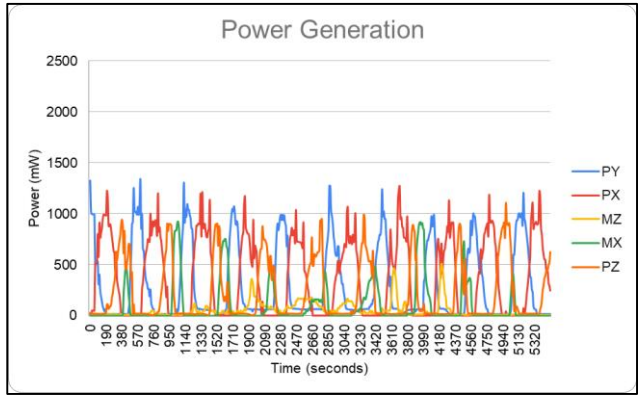
| Date | June 1, 2021 | July 9, 2021 | July 17, 2021 |
|---|---|---|---|
| Beta angle | 0 deg | 50 deg | 70 deg |
| Power Generated | 1,790 mWh | 1,658 mWh | 1,560 mWh |

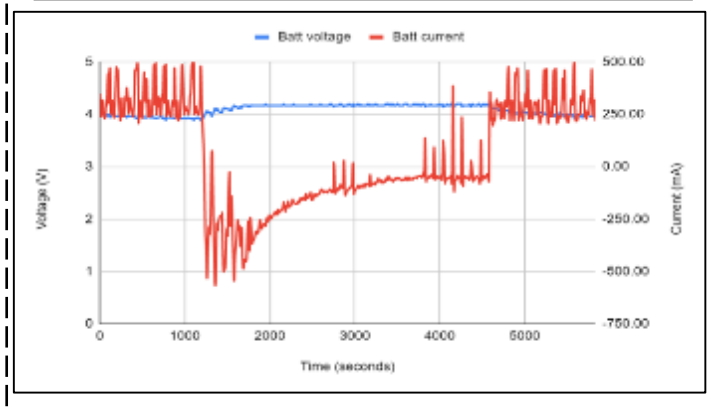
Conditions
- 5 panels working
- GPS is OFF
- Battery heater is OFF

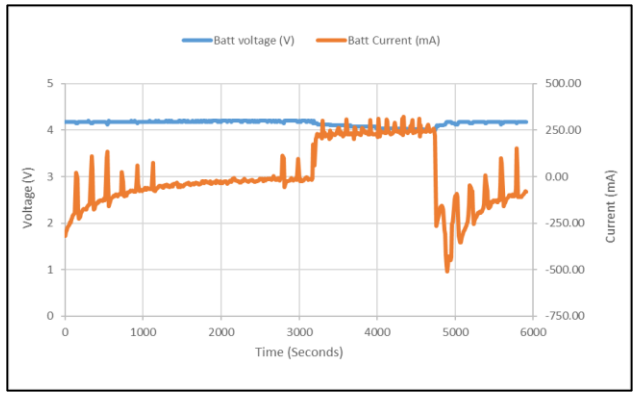
Observation
- Generated power is highest at 0 deg beta angle

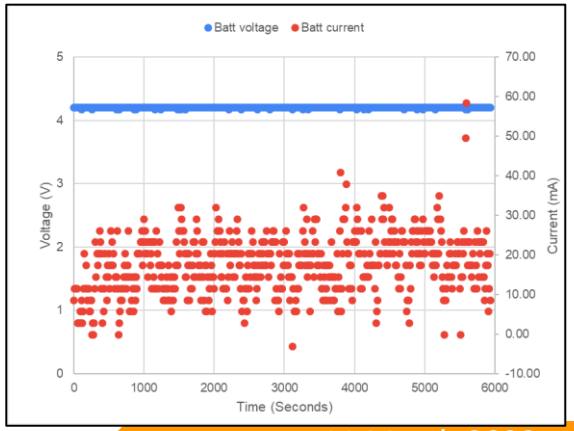


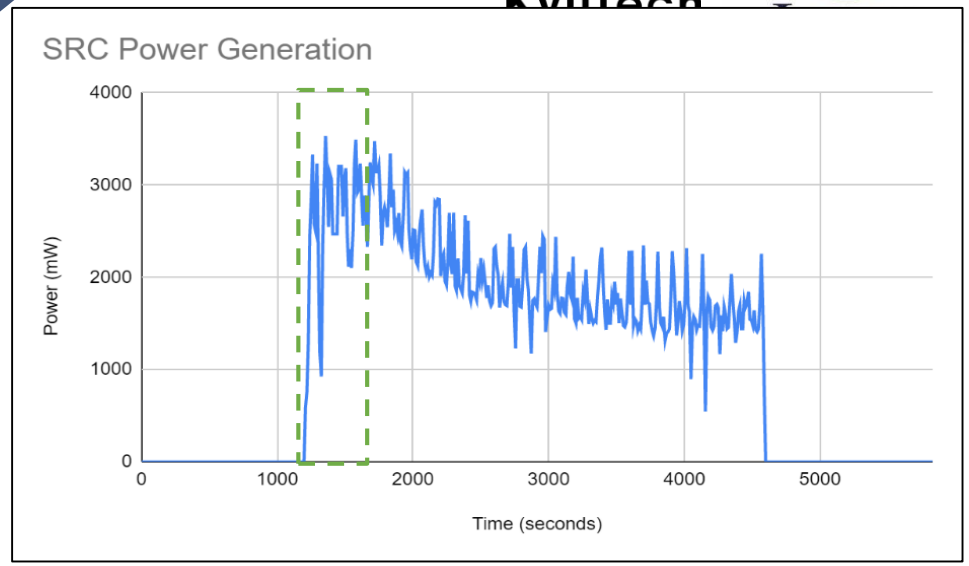



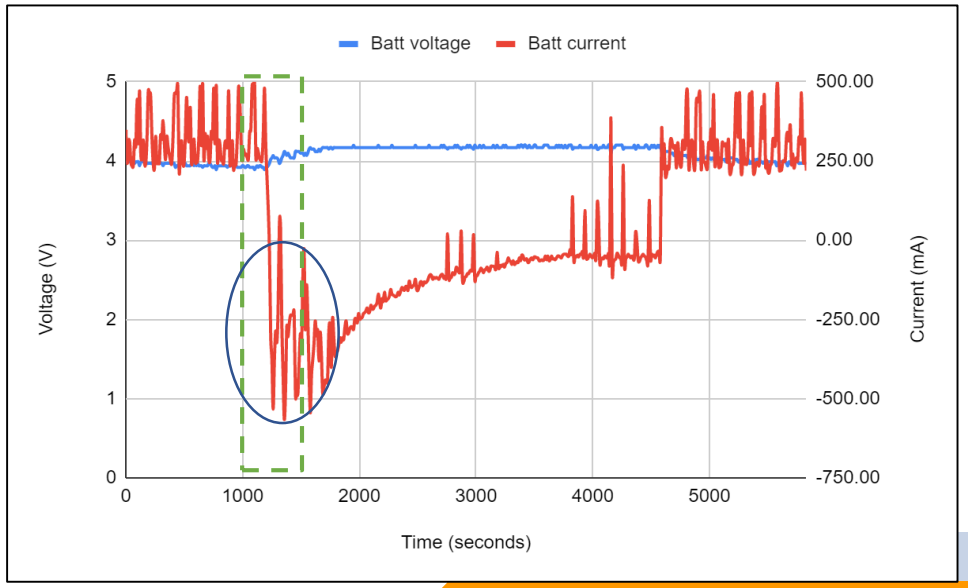



# Available power to the load at 0 deg Beta angle (Tsuru on-orbit data)

- At 0 deg Beta angle, sunlit period is at 3,380 seconds (~56 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 2,670 mW.

| **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**<br>**E = [(A - B)*C] - D** | mWh | 1,604 | 1,240 | 878 |



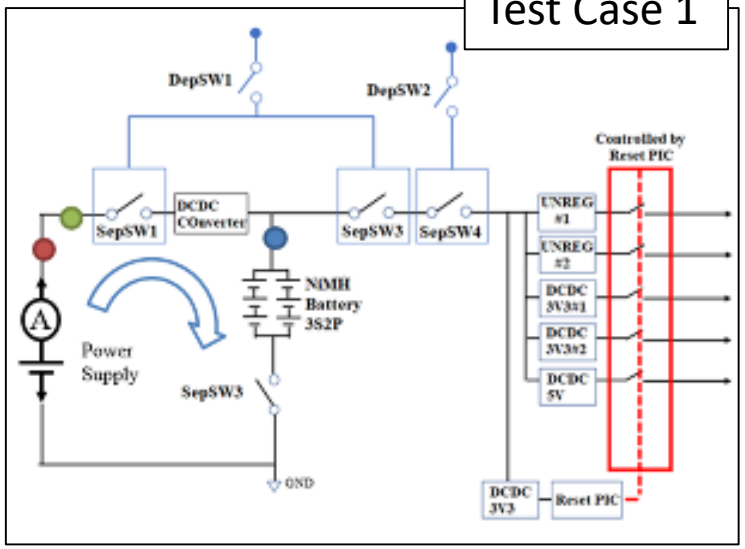



# BIRDS-4 EM satellite test (1/2)

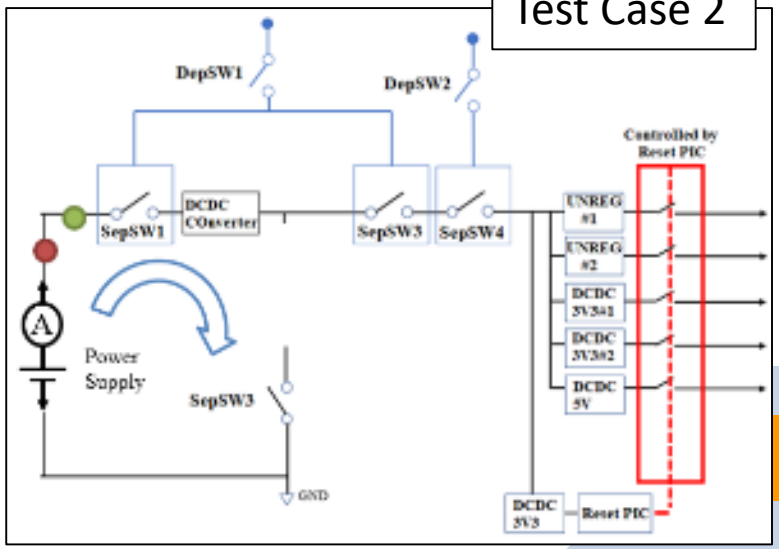
- EM satellite was used to verify the power consumption.
- Test cases
  1. With fully-charged battery
  2. Without battery
- Test setup:
  - antenna deployed
  - all internal boards are connected to the backplane
  - no solar panels
  - regulated power (4.2 V) supplied to the satellite through FAB J5 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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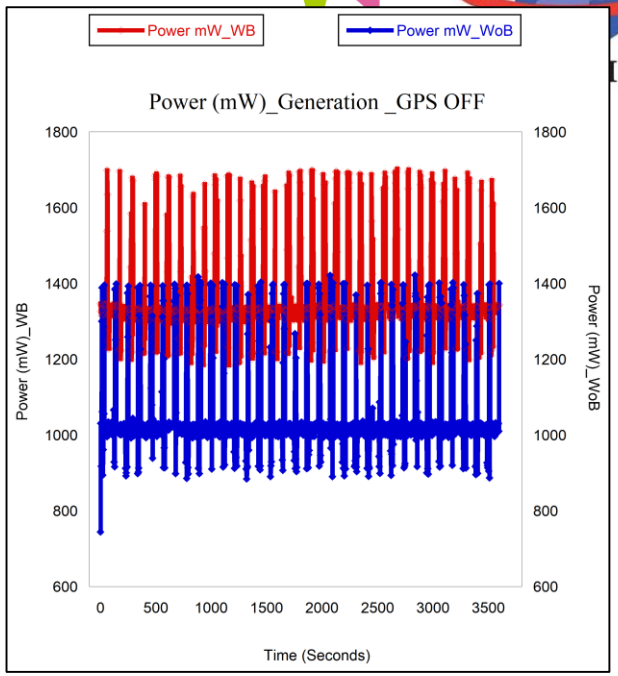
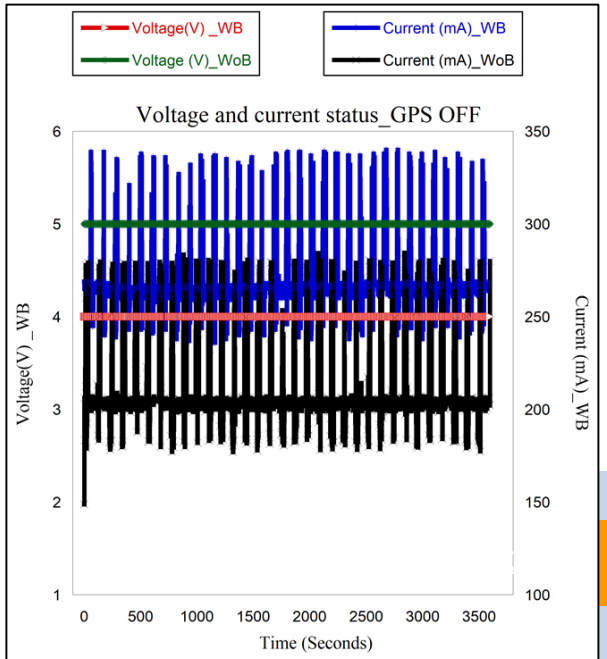
# BIRDS-4 EM satellite test result (2/2)

| 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**<br>**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

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# Observation (On-orbit and Ground test)

- For on-orbit at worst case, the available generated energy is 1604 mWh (at 5 solar panels) >>page 7
- And, according to ground test results the available energy 1133 mWh >>page 8
- The results of the on-orbit and ground tests are not exactly equivalent. The battery was fully charged and receiving constant power from an external power source during the ground test setup evaluation. At this test, the battery did not require a lot of power to fully charge. Thus, the power generation was relatively low.

# Summary and Conclusion

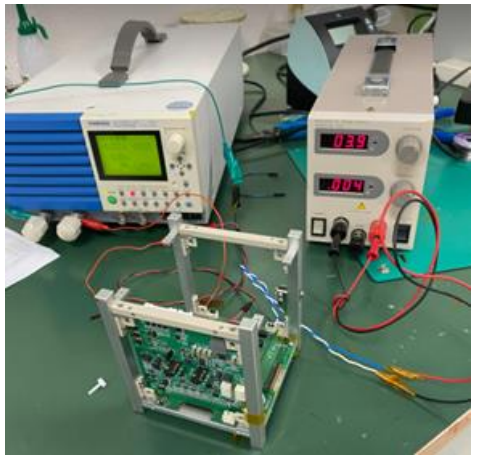
- Focus on power budget reliability based on flight data rather than simulation. The estimated power generation in one orbit is 2500mWh in one orbit and the available power to the load is 1600mWh for the case of 5 solar panels working (see page 7).
- Estimate the Power Generation from the satellite in the worst-case (Low Beta) ; please follow page no.7
- 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; please see the table on page number 7.
- 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.
- Power generation can vary depending on the satellite's TLE (high or low beta angle), initial orientation, rotation speed, and other parameters.

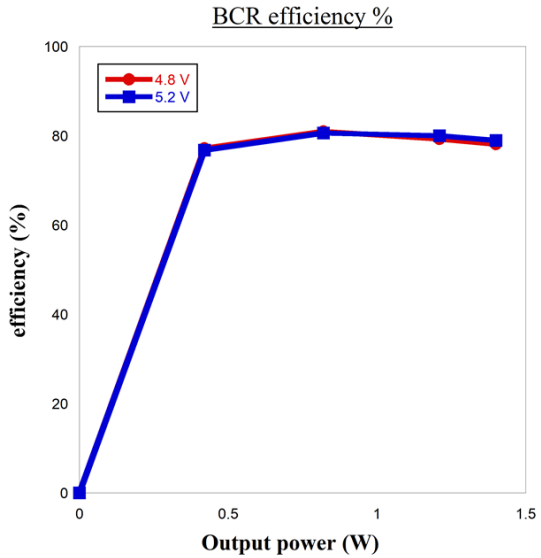
# Acknowledgements


- Prof. Mengu Cho
- IZ , Adolfo , Marloun, BIRDS members

❑ Appendix

# Blocking Diode and BCR Characterization

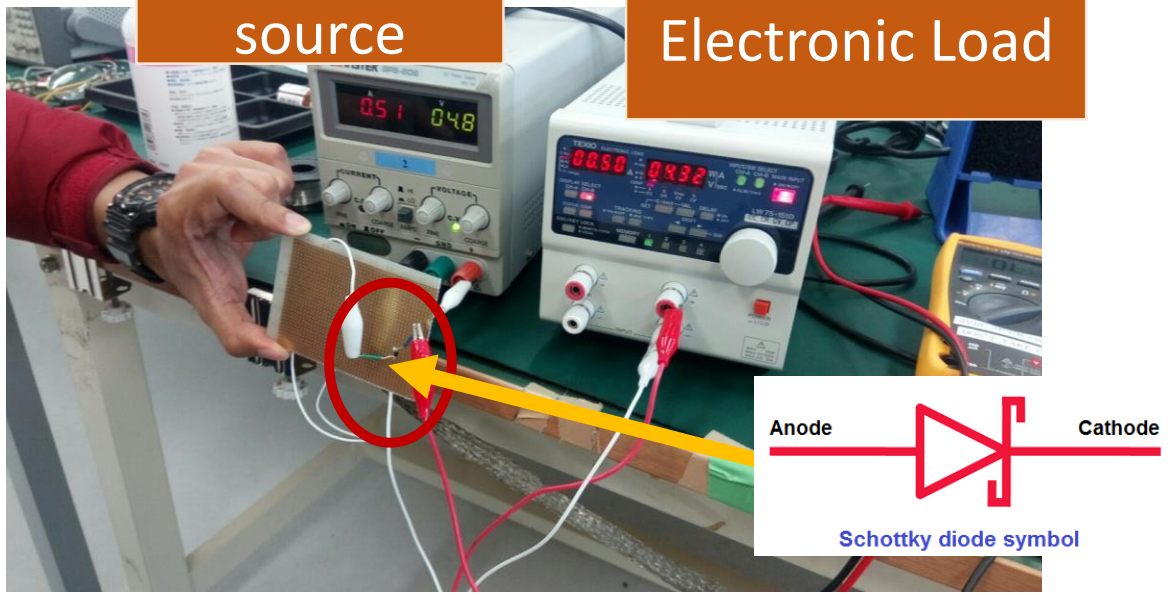





- Efficiency % = (Output power (w)/ Input power (W))X100%

Test condition,

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




Test appearance

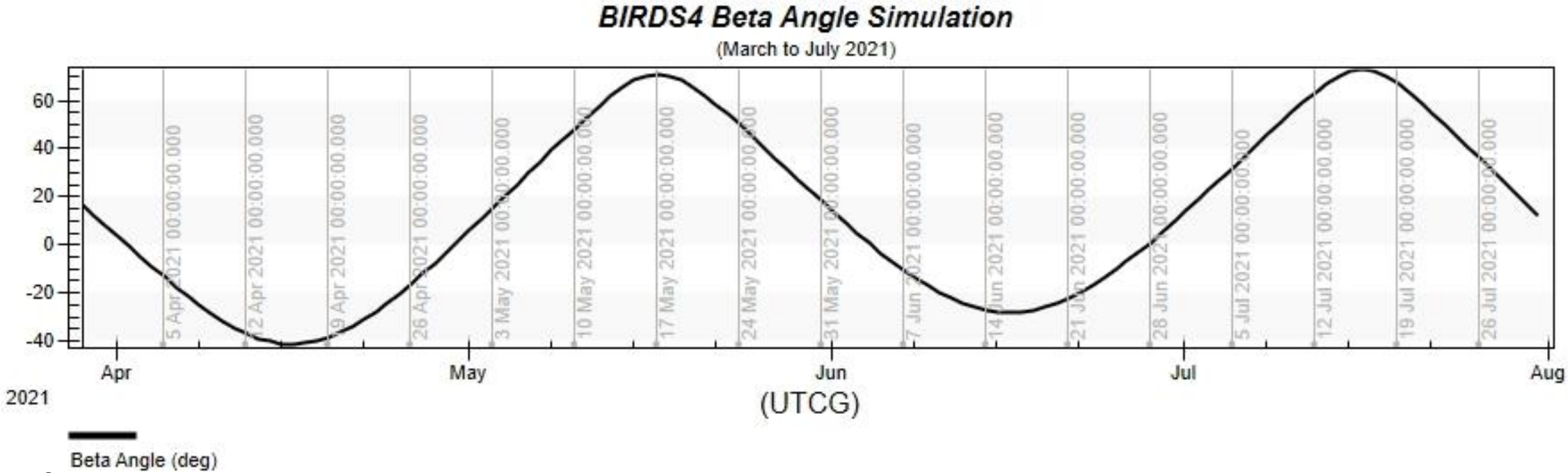
- Voltage source =4.8 V
- Consume current by electronic load by= 0.5 A
- Voltage drop=0.48 V
- Power loss= 240mW

# Beta Angle Prediction (March to July 2021)

Parameters:

Elevation = 416.86 km

Inclination = 51.6444 deg

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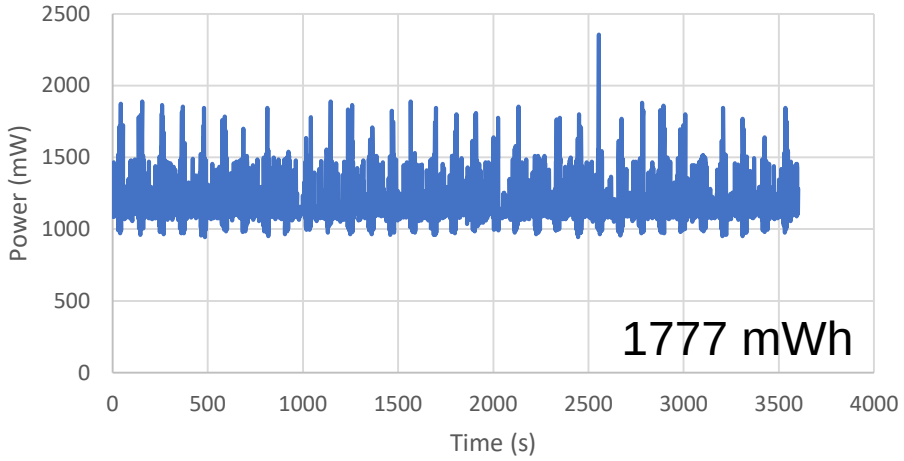
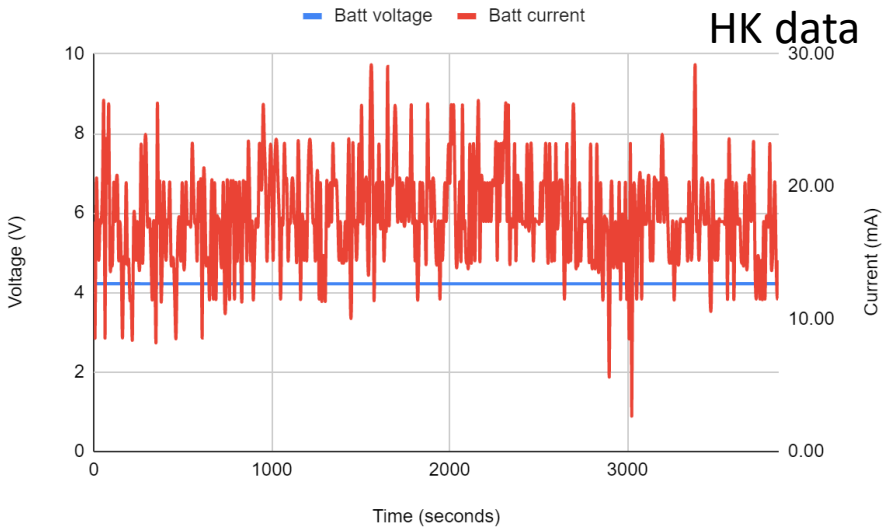
# Test without battery connected (GPS ON, heater OFF)

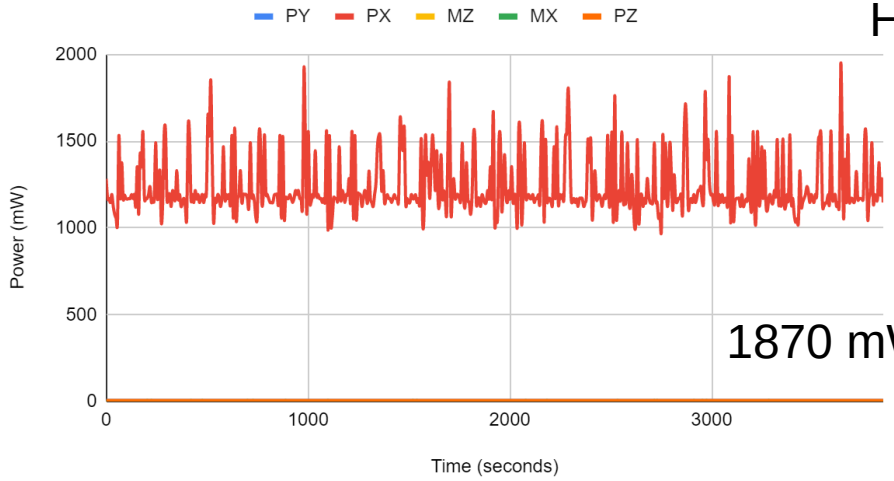
Power consumption (no Battery) Current probe



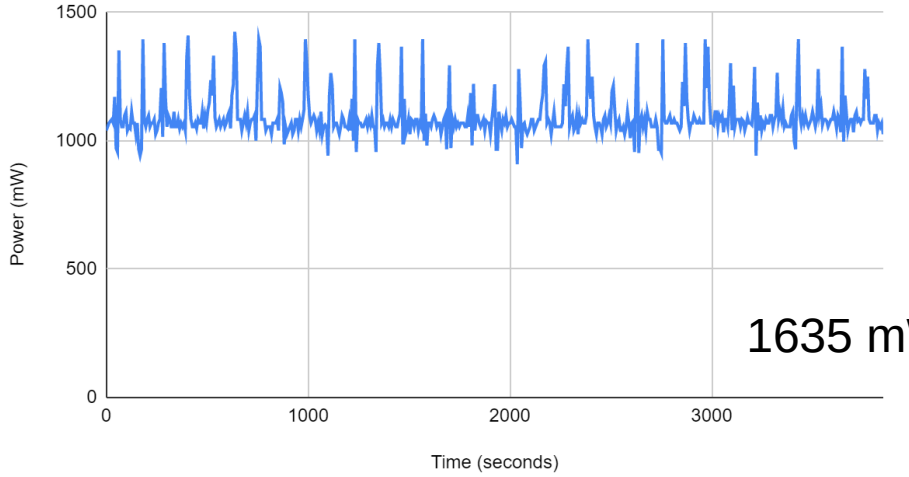

HK data




Power Generation HK data

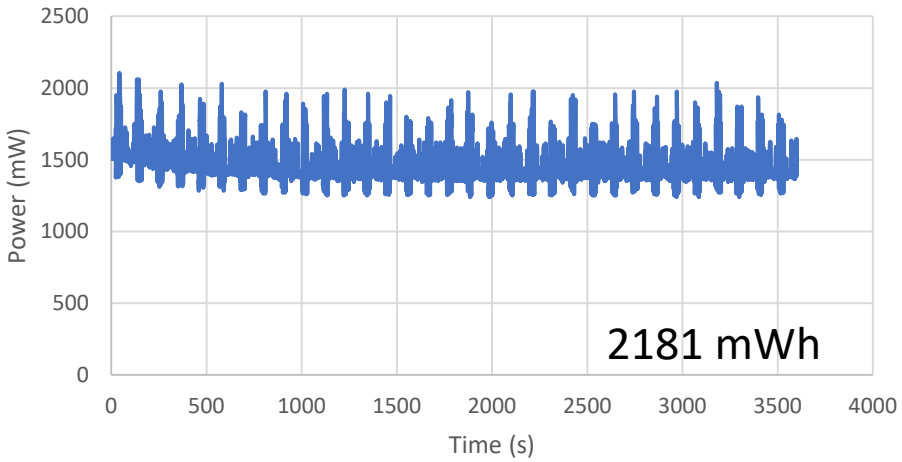



SRC Power Generation HK data

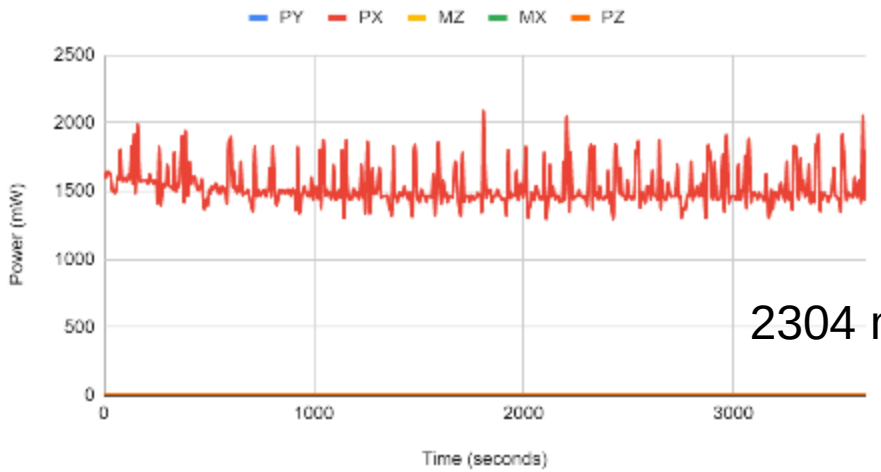


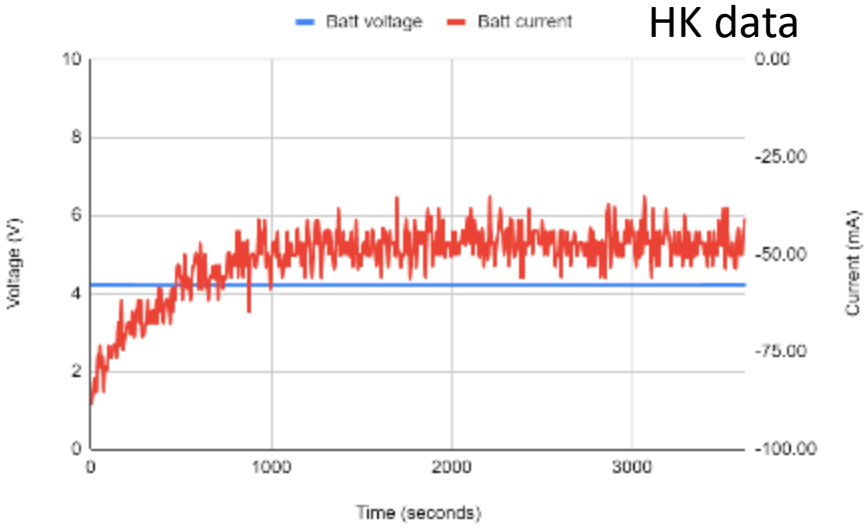
# Test with battery connected (GPS ON, heater OFF)

Power consumption (with Battery) Current probe



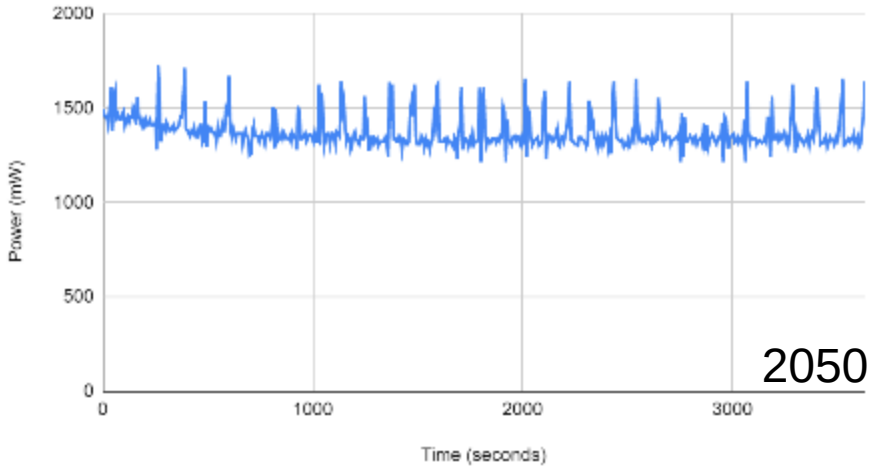

Power Generation HK data



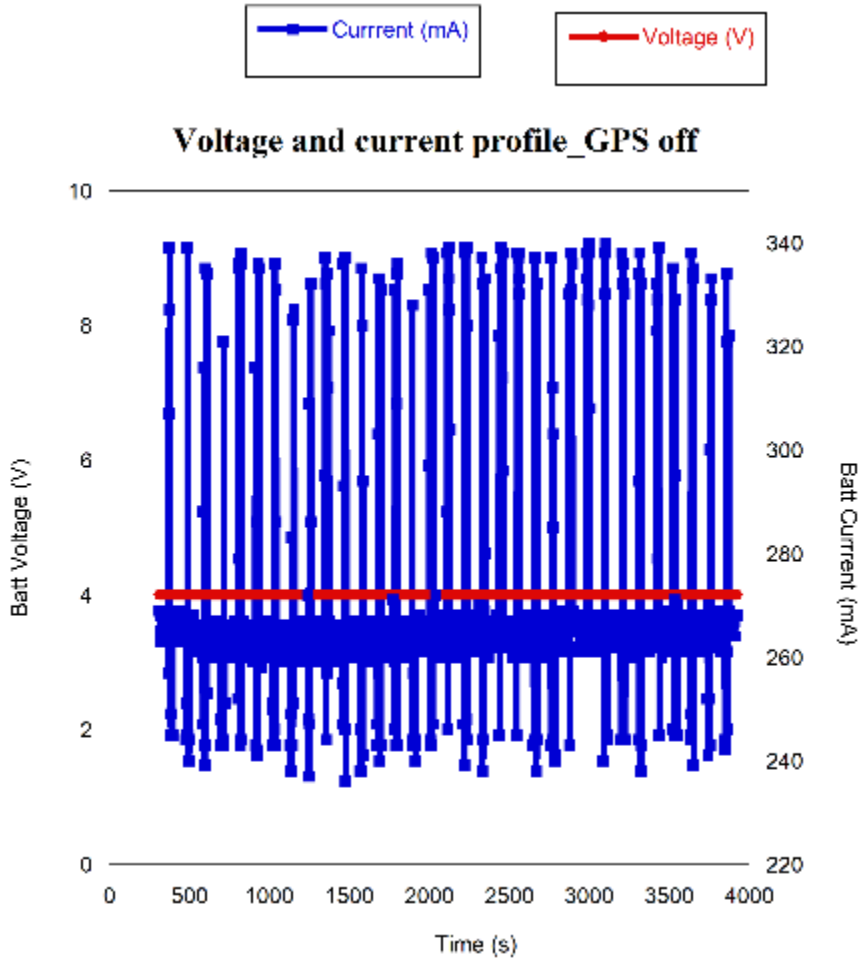



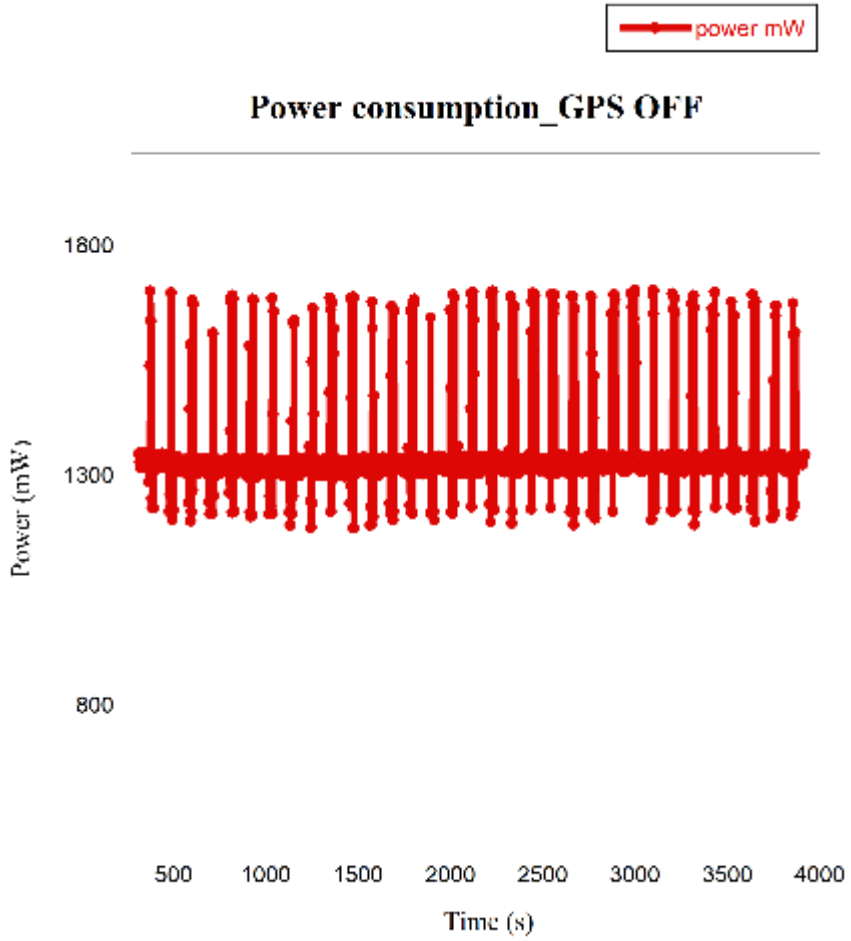

HK data

SRC Power Generation HK data

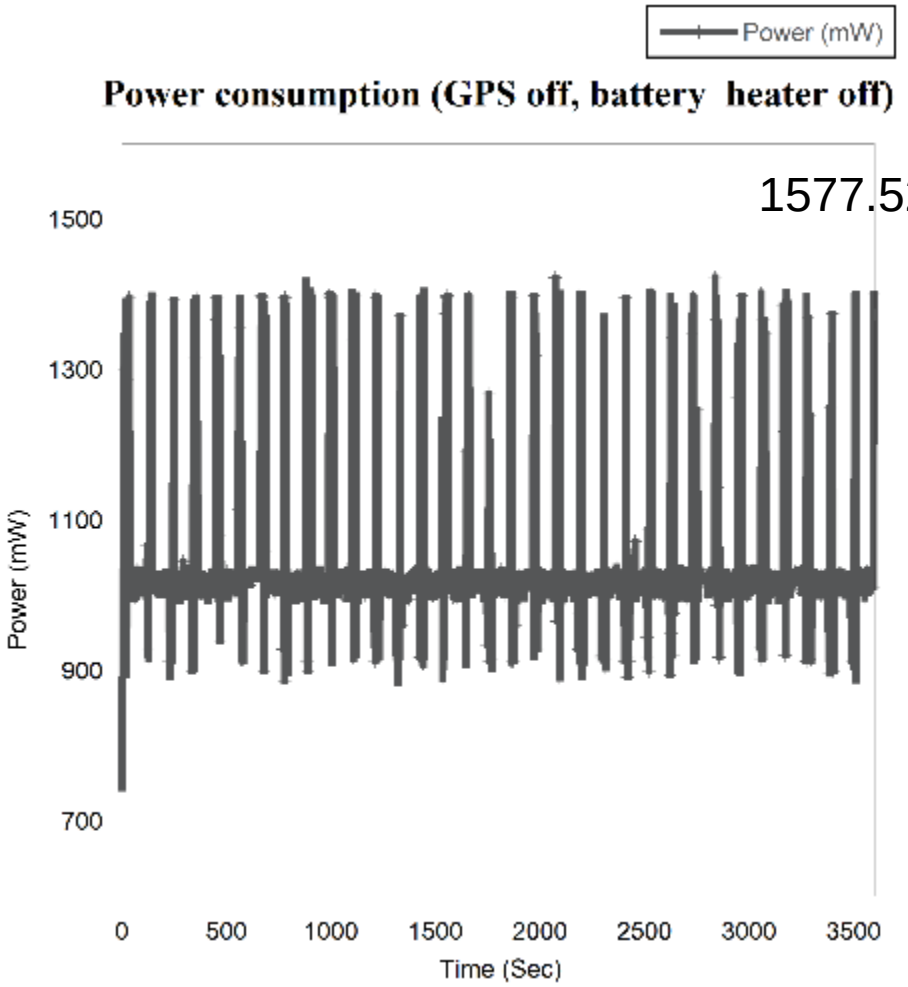


# Test with battery connected (GPS OFF, heater OFF)

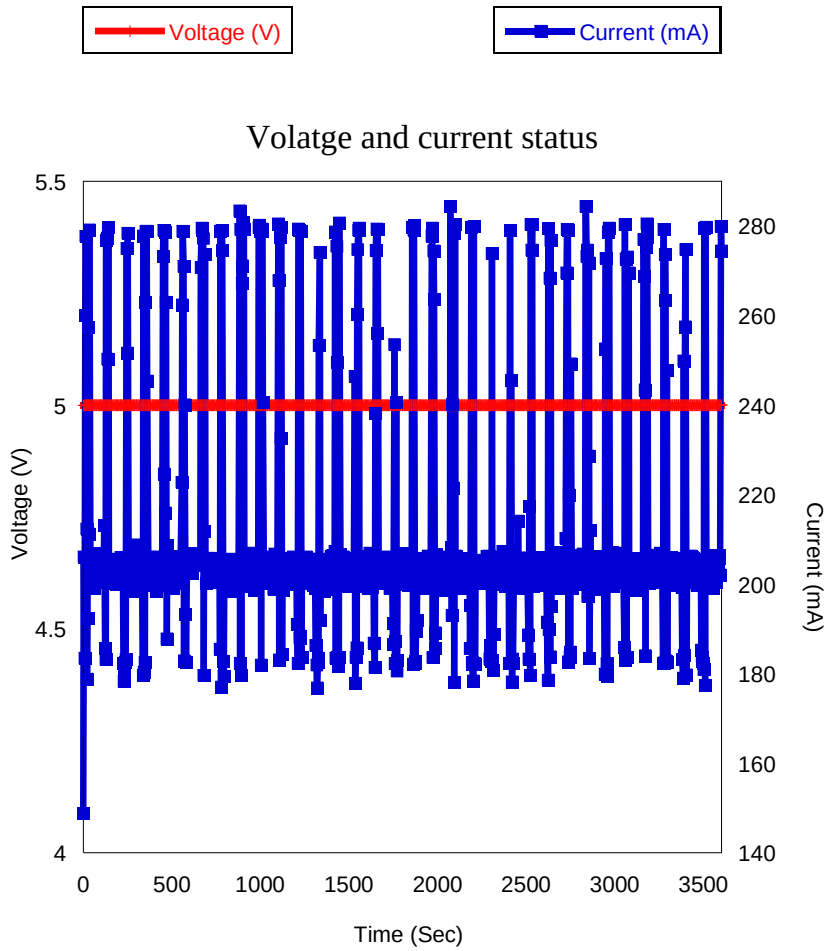


# Test without battery connected (GPS OFF, heater OFF)




1577.52 mWh in one orbit

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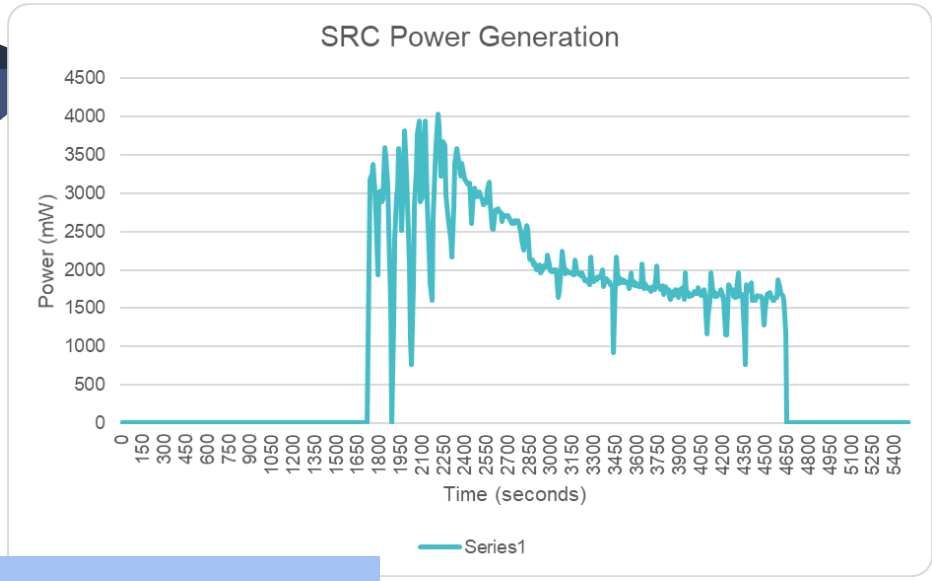
# BIRDS-4 power calculation

| | Energy generation mWh | | |
|---|---|---|---|
| | 5 panels | 4 panels | 3 panels |
| BIRDS-4 (March 28 2021) | 1775.8280 | 1470 | 937 |




| Power Generation per Orbit individual panels | | | | | | |
|---|---|---|---|---|---|---|
| Sample Time (s) | Total py (mWh) | Total px (mWh) | Total mz (mWh) | Total mx (mWh) | Total pz (mWh) | Total (mWh) |
| 10 | 403.0425365 | 411.1782527 | 327.8563864 | 328.328226 | 282.2613355 | 1752.666737 |

| Power Generation per Orbit SRC (mWh) | 1775.828002 |
|---|---|

calculation:

During sunlight: Solar power output energy, Esrc = Pbat +Pload
Source energy from solar panels= 1775.828002 mWh ,enter the BCR
From google sheet analysis= Energy after BCR= 1540.869959 mWh
Loss= 13.2309 %
One orbit Load only = (918.34 30606/sunlight + 799.1807969/eclipse)=1717.5235 mWh

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Total power consumption is 1717.5235 mWh per orbit

# Power consumption calculation

on March 28 2021

Psrc : Isrc*Vsrc — during sunlite

Pbat : Ibat*Vbat — during eclipse

Praw : Iraw*Vraw — time

BCR efficiency — (After Pbat+Pload) 86.769099 — 80% from measurement

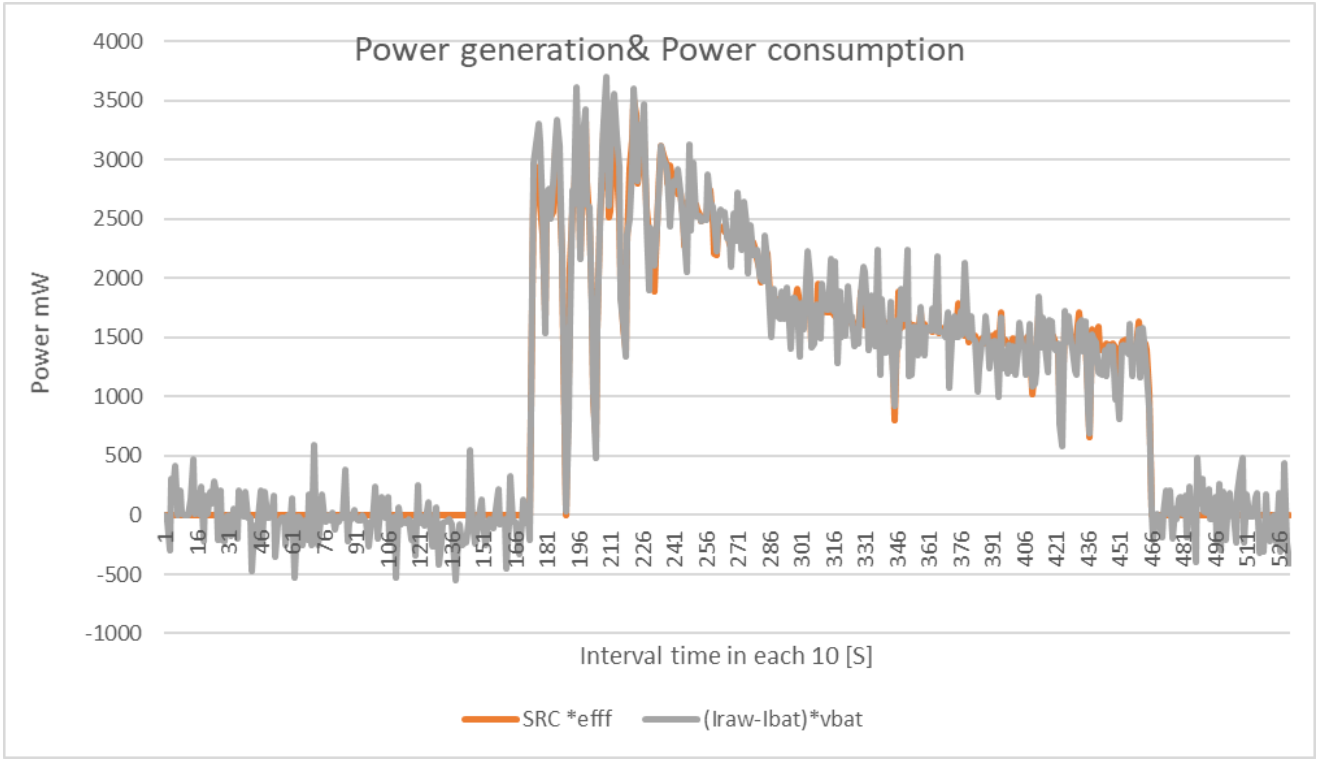
Sunshine period: 63 min
Eclipse period: 28 min

| | |
|---|---|
| Total energy generation in one-orbit (mWh) | 1775.828002 |
| Total energy available after BCR in one orbit (Psrc)*efficiency, E1 mWh | 1420.662402 |
| Total energy consumed by the load in sunshine (Praw), E2 (mWh) | 918.3430606 |
| Total energy consumed by the load in eclipse (Praw), E3: (mWh) | 799.1807969 |
| Total energy stored to the battery in sunshine( Pbat), E4: (mWh) | 637.4935269 |
| Total energy released from the battery in eclipse (Pbat), E5: mWh | 568.3113267 |
| The energy surplus in one orbit E1-(E2+E3)+(E4-E5): mWh | 127.4863337 |

All the energy calculation are based in Time integral value

# Isrc, Iraw & Ibat in the same orbit.

calculate the total power generated using the newly calibrated




SRC*efficiency = (Iraw-Ibat)*Vbat