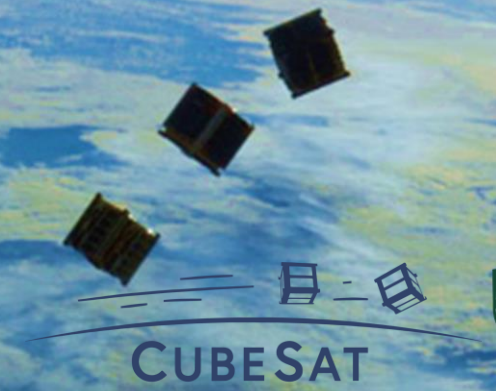
ACCEPTANCE SCREENING AND CELL MATCHING: ACHIEVING OPTIMAL COTS LI-ION BATTERY PERFORMANCE FOR SPACE APPLICATIONS

26 April 2023



*Hari Ram Shrestha ,D3 student

Co-supervisor, Dr. Takashi Yamauchi

Supervisor, Prof. Dr. Mengu Cho

Cho lab, LaSEINE Kyushu Institute of Technology, Tobata, Kitakyushu, Fukuoka, Japan

*Shrestha.hari-ram852@mail.kyutech.jp

Pic credit: ISS/JAXA/NASA

Contents

KyuTech BIRDS Satellite Project

The Joint Global Multi-Nation is **BIRDS** Satellite Project since 2015

Targets for non-space fairing countries

BIRDS Satellite project purposes:

- To design, build, test, launch, and operate the participation country first satellite and providing continuity to other who already deploy their nation`s previous satellite.
- Interdisciplinary, Human Network, Collaboration, Capacity build up, Ground station network

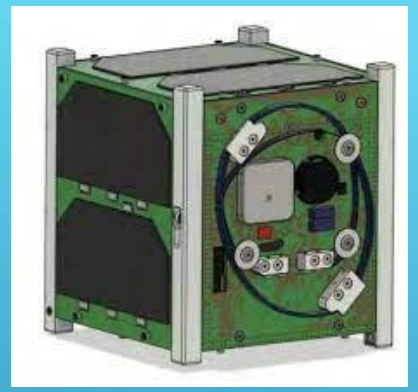
Principal Investigator (PI) is Professor Dr. Mengu Cho

Awards

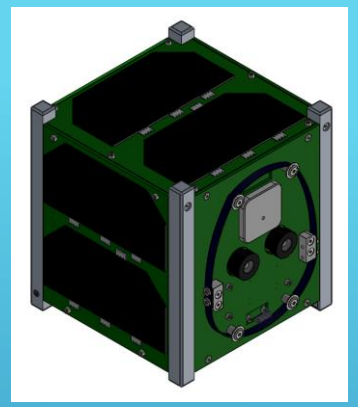
Kyutech Tobata Campus

*https://www.kyutech.ac.jp/english/about/map/access.html

Introduction : Kyutech's satellites & used battery



BIRDS-1



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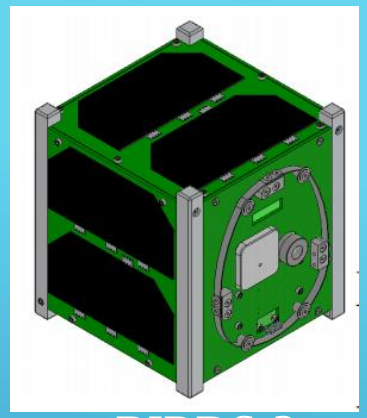

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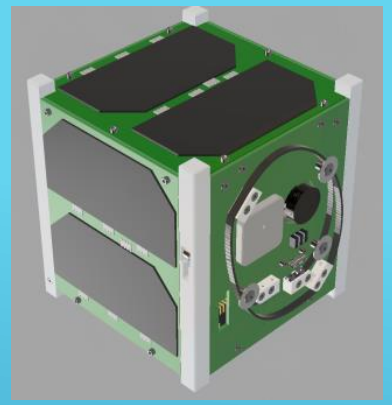

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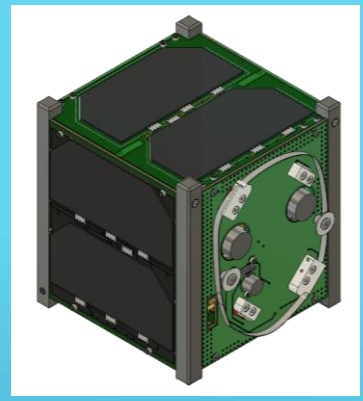


BIRDS-5

NiMH

	BIRDS Satellite	KITSUNE
Type:	Nickel-Metal Hydride Battery(eneloop),Panasonic	Lithium Ion Battery, Sanyo NCR 18650 GA
Configuration	3 series 2 parallel (3S2P)	2series3parallel (2S3P)
Capacity:	3,800 mAh	10,350 mAh
Nominal Voltage:	1.2V * 3 = 3.6V	3.6*2= 7.2 V
Weight:	27g * 6 = 162g	48 g*6=288g
Size cell :(Diameter) x (Height):	14.35(D) x 50.4(H) mm	18.5(d)mmx65.3 (H)

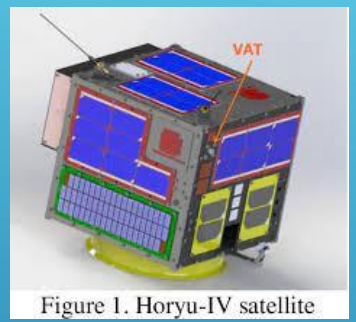


Figure 1. Horyu-IV satellite

Li-Ion

KITSUNE, 6U

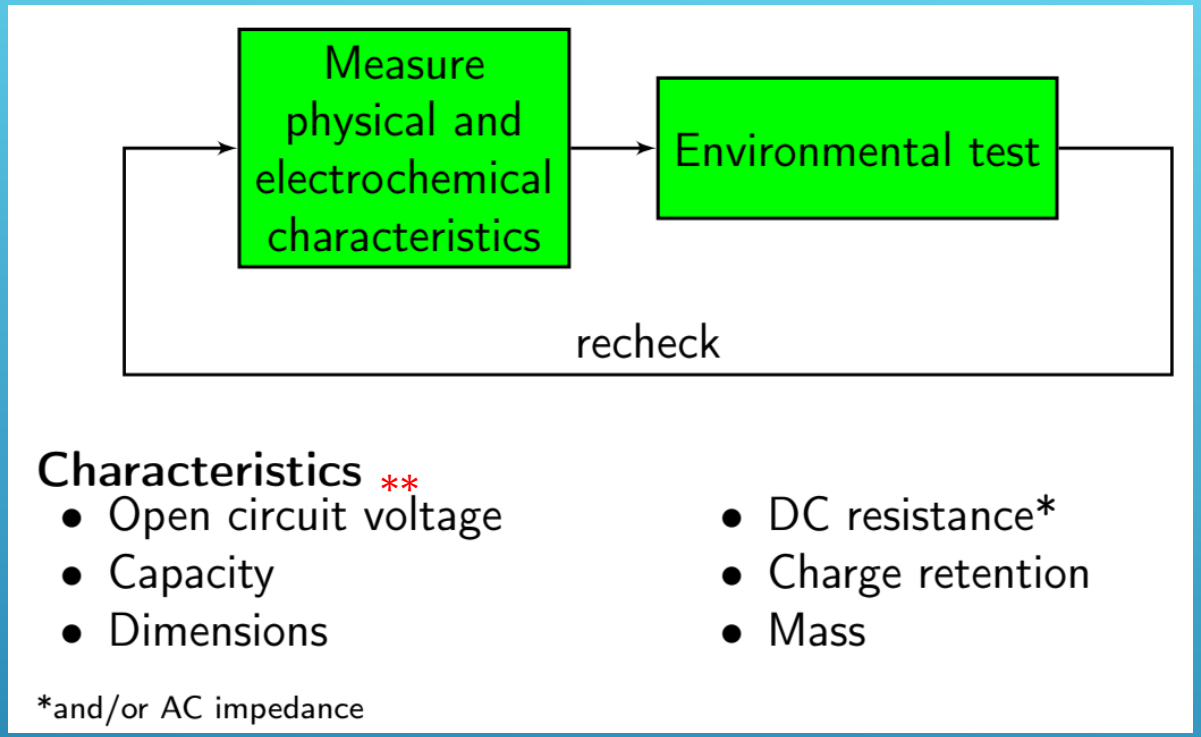
Pic: by Kyutech

Screening and cell matching

- To construct the space applicable battery from COTS* Li ion /NiMH or other battery cells.
- And, it is subjected to acceptance screening and cell matching tasks before to the assemble battery.

Acceptance screening of Cells

- It consist of a baseline of physical and electrochemical tests** that are re-checked before and after the environmental tests

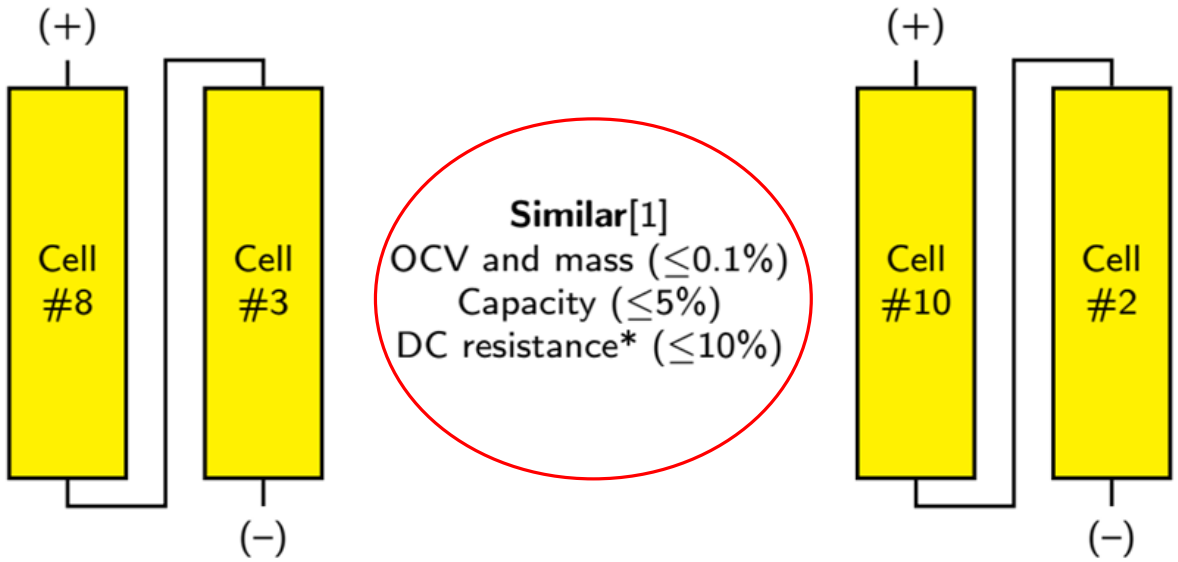


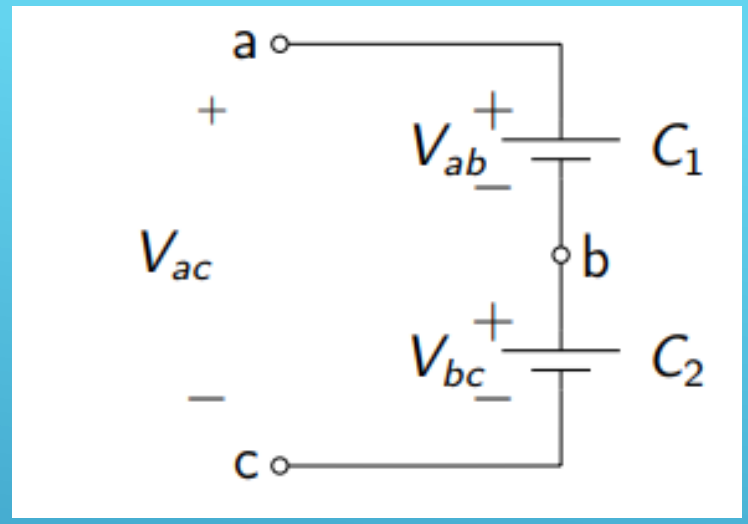
OBJECTIVE

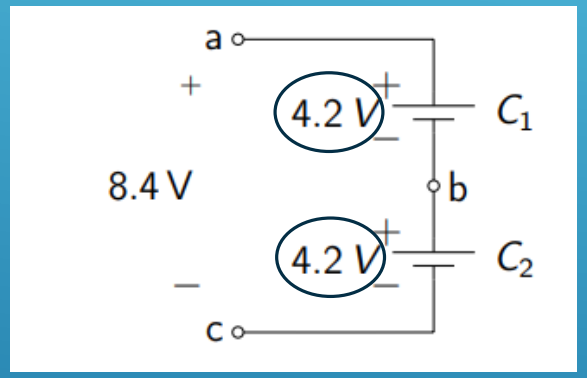
- Find defects
- Assemble the best batteries

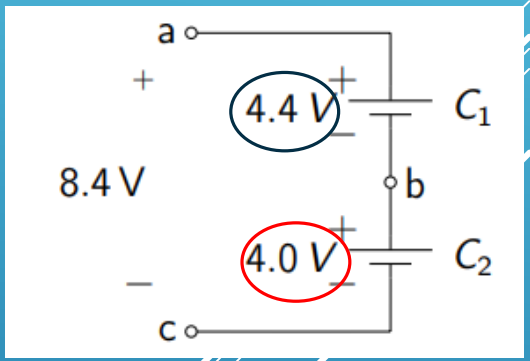
*Commercial off -the- shelf

Cell matching process









OBJECTIVE

- Avoid unbalanced voltages
- Mitigate the state - of -charge imbalance

Risk:

Overcharge
External short
Internal short
Over discharge
High temperatures

Thermal runway

How Does it work?

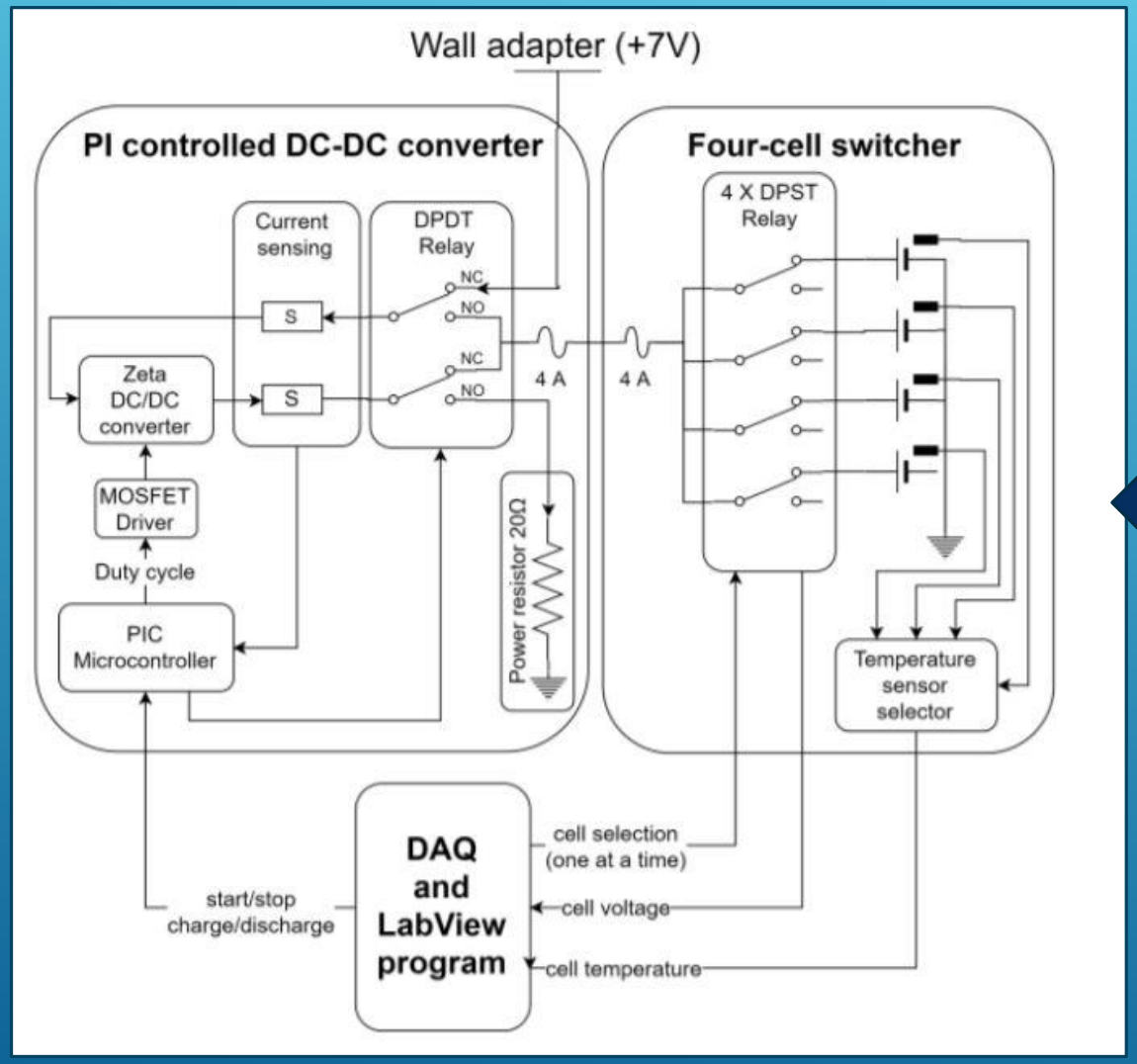


Fig: charger discharger system working diagram

State 1:Converter work as a buck converter

- Relay is set in charging position(NC),the power source is connected to the converter input and the cell switcher is connected to the output.

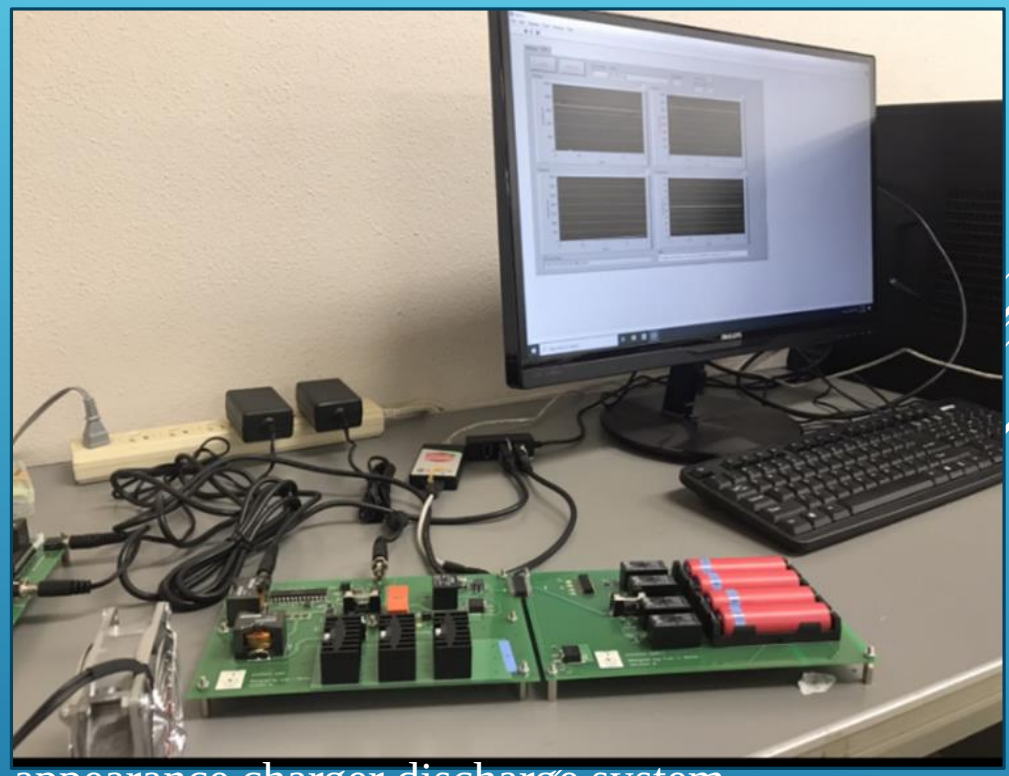


Fig: real appearance charger discharge system

State 2:Converter work as a boost converter

- Relay is set in discharging position(NO),the cell switcher is connected to the input and power resistor is connected to the output.

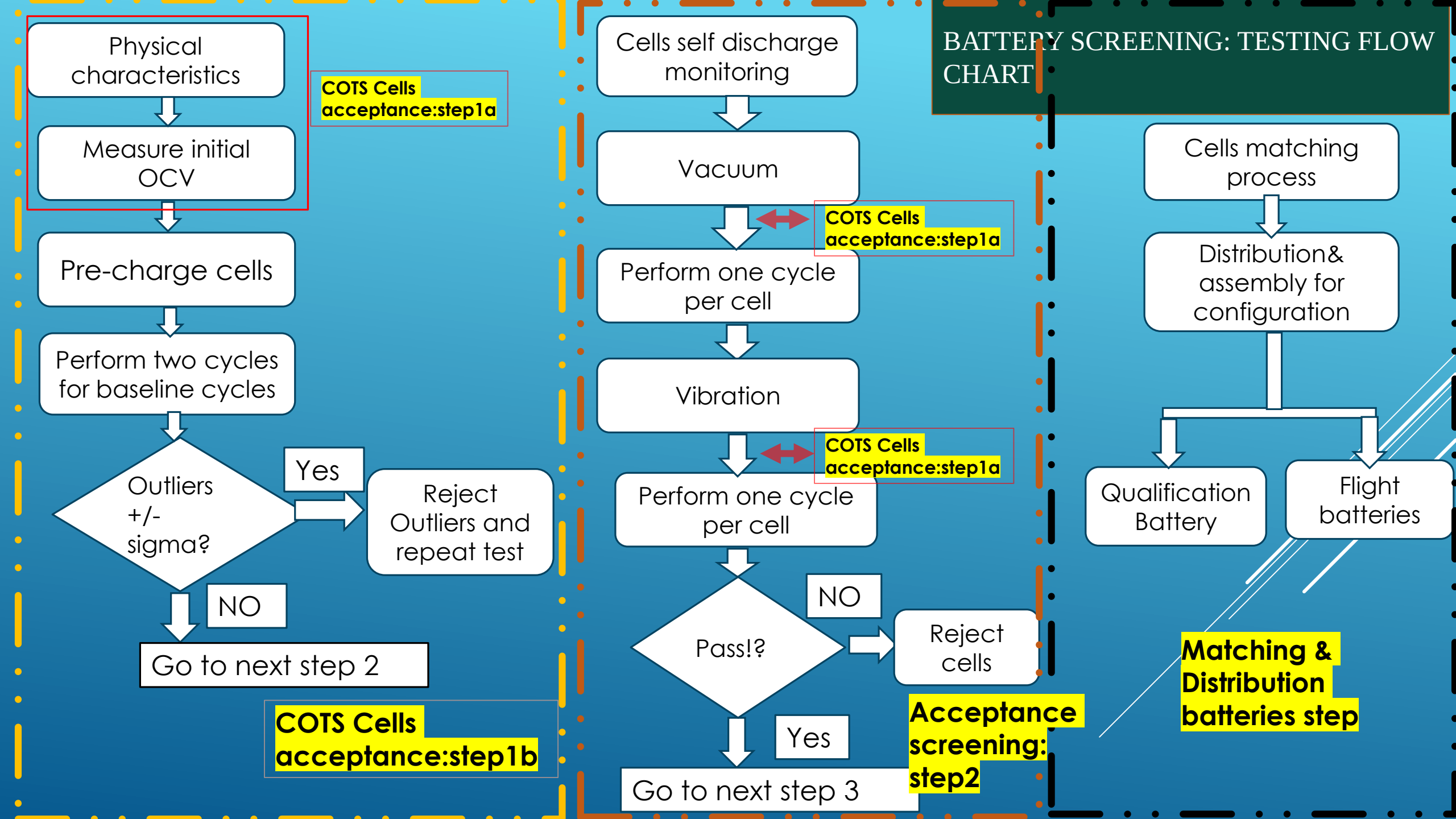
Charge/Discharge system with four cell switcher

- A charge/discharge system is a system to assist cell matching and construction of a custom battery using COTS cells. The cells are screened on the system and generates the required data

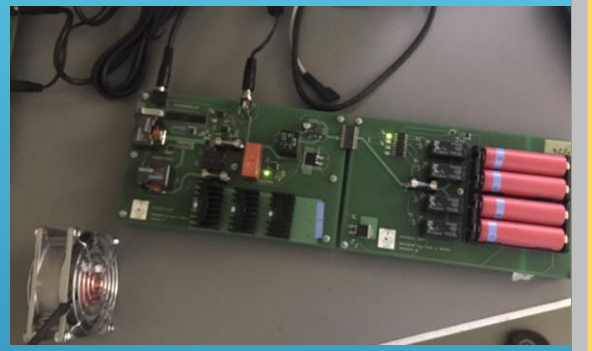
- The system is used to screen and get acceptable batteries after checking the physical and electrochemical characteristics of each cell after every test (Thermal vacuum and Vibration Test)

- The screening system shall fulfill the safety review requirement for launch providers.

BATTERY SCREENING: TESTING FLOW CHART



Cycles test and Environmental test



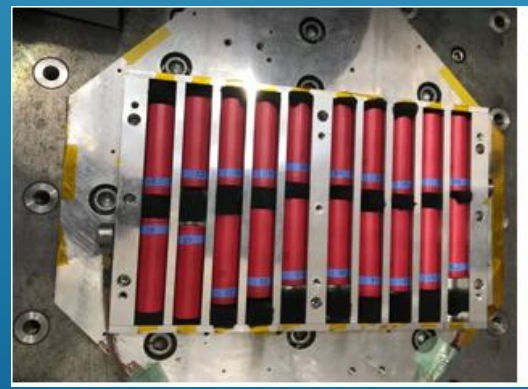
Cell screening steps:
1.Pre discharge
2.Full charge
3.Full discharge
4.Post Charge
Total time for test: 17 hours for 4 batteries

Vacuum Test

Vacuum	Temperature	Time
< 1x10^-3 Pa	20 – 25 degree C	6 hour

Random Vibration Level for Li ion battery

Axis	Frequency (Hz)	PSD (G2/Hz)	Acceleration (Grms)	Time (sec)
All	20	0.020	8.6	60
	80	0.080		
	350	0.080		
	2000	0.014		



Environmental test-before vacuum test and after vibration test data and results

Table: **KITSUNE** batteries results based Physical measurements: Length (mm) OCV (V),mass(mg) ,Diameter(mm)

- **All batteries are PASSED based on physical character measurements.**

N	Before					After					Difference				Statu
	OCV	Length [mm]	Diameter [mm]	Mass [g]	Visual Ins.	OCV (vibration)	Length [mm]	Diameter [mm]	Mass [g]	Visual Ins.	OCV [<0.1%]	Length [<1%]	Diameter [<1%]	Mass [<0.1%]	
13	3.745	64.95	17.95	47.27	OK	3.747	65.02	18.00	47.29	OK	0.05%	0.11%	0.28%	0.04%	PASS
14	3.746	64.91	17.98	47.25	OK	3.747	65.00	18.09	47.21	OK	0.03%	0.14%	0.61%	0.08%	PASS
15	3.740	64.94	18.00	47.23	OK	3.742	65.02	18.01	47.22	OK	0.05%	0.12%	0.06%	0.02%	PASS
16	3.741	64.96	18.02	47.29	OK	3.740	65.02	18.20	47.28	OK	0.03%	0.09%	1.00%	0.02%	PASS
17	3.733	64.95	17.95	47.43	OK	3.736	65.02	17.99	47.42	OK	0.08%	0.11%	0.22%	0.02%	PASS
18	3.742	64.97	17.98	47.29	OK	3.741	65.03	18.00	47.28	OK	0.03%	0.09%	0.11%	0.02%	PASS
19	3.740	64.95	18.01	47.25	OK	3.739	65.01	18.04	47.24	OK	0.03%	0.09%	0.17%	0.02%	PASS
20	3.746	64.97	18.00	47.24	OK	3.744	65.03	18.15	47.23	OK	0.05%	0.09%	0.83%	0.02%	PASS
21	3.739	64.96	17.98	47.21	OK	3.740	65.01	18.08	47.24	OK	0.03%	0.08%	0.56%	0.06%	PASS
22	3.742	64.97	17.97	47.35	OK	3.740	65.02	18.06	47.38	OK	0.05%	0.08%	0.50%	0.06%	PASS
24	3.748	64.96	17.99	47.19	OK	3.746	65.03	18.00	47.23	OK	0.05%	0.11%	0.06%	0.08%	PASS
26	3.746	64.94	17.90	47.23	OK	3.745	65.03	18.00	47.24	OK	0.03%	0.14%	0.56%	0.02%	PASS
27	3.747	64.99	17.99	47.25	OK	3.745	65.02	18.05	47.27	OK	0.05%	0.05%	0.33%	0.04%	PASS
28	3.745	64.97	18.03	47.23	OK	3.745	65.02	18.00	47.22	OK	0.00%	0.08%	0.17%	0.02%	PASS
29	3.745	64.97	18.03	47.31	OK	3.743	65.03	18.10	47.32	OK	0.05%	0.09%	0.39%	0.02%	PASS
34	3.735	64.96	17.95	47.36	OK	3.738	65.01	18.07	47.37	OK	0.08%	0.08%	0.67%	0.02%	PASS
35	3.740	64.97	17.96	47.20	OK	3.739	65.03	18.10	47.22	OK	0.03%	0.09%	0.78%	0.04%	PASS

Environmental test-before vacuum test and after vibration test data and results

Table: KITSUNE batteries results based on charged and discharge DC resistance [Internal Impedance] (mΩ)and Capacity (mAh)

Failure rate of battery during test,
Total batteries (cells) are 23
No 1 to 12 were used for EM satellite,
5/36 =14%

before and after screening tests, changed the battery internal resistance and capacity

KITSUNE Cell Screening - Environmental Test

N	Before				After				Difference				Status
	Charged		Discharged		Charged		Discharged		Charged		Discharged		
	DC Res	Capacity	DC Res	Capacity	DC Res	Capacity	DC Res	Capacity	DC Res	Capacity	DC Res	Capacity	
	[mΩ]	[mA/h]	[mΩ]	[mA/h]	[mΩ]	[mA/h]	[mΩ]	[mA/h]	[<10%]	[<5%]	[<10%]	[<5%]	
13	71.90	3017.50	90.70	3341.00	75.00	3018.20	93.00	3345.00	4.31%	0.02%	2.54%	0.12%	PASS
14	73.40	3054.50	95.70	3355.00	75.30	3017.60	98.80	3341.00	2.59%	1.21%	3.24%	0.42%	PASS
15	73.80	3036.90	93.40	3343.00	72.30	3035.10	91.50	3352.00	2.03%	0.06%	2.03%	0.27%	PASS
16	73.40	3065.00	94.60	3371.00	75.30	3006.60	95.30	3351.00	2.59%	1.91%	0.74%	0.59%	PASS
17	68.00	3117.00	95.70	3373.00	70.70	3050.30	94.60	3373.00	3.97%	2.14%	1.15%	0.00%	PASS
18	75.00	3055.70	92.60	3359.00	71.10	3035.80	93.00	3358.00	5.20%	0.65%	0.43%	0.03%	PASS
19	73.00	3084.40	91.10	3363.00	72.30	3028.40	96.50	3342.00	0.96%	1.82%	5.93%	0.62%	PASS
20	81.90	3046.50	97.60	3355.00	77.60	3002.20	97.60	3339.00	5.25%	1.45%	0.00%	0.48%	PASS
21	75.70	3054.50	96.10	3367.00	72.60	3041.10	95.30	3363.00	4.10%	0.44%	0.83%	0.12%	PASS
22	77.30	3075.50	96.50	3387.00	71.10	3056.80	91.10	3383.00	8.02%	0.61%	5.60%	0.12%	PASS
23	80.00	3066.40	94.20	3368.00	69.20	3045.10	90.00	3364.00	13.50%	0.69%	4.46%	0.12%	FAIL
24	73.40	3084.60	89.60	3360.00	70.00	3030.20	93.40	3342.00	4.63%	1.76%	4.24%	0.54%	PASS
25	78.40	3029.20	99.20	3356.00	70.70	3012.10	91.50	3359.00	9.82%	0.56%	7.76%	0.09%	PASS
26	74.60	3069.80	96.50	3363.00	71.10	3032.00	95.00	3344.00	4.69%	1.23%	1.55%	0.56%	PASS
27	73.80	3036.90	93.40	3343.00	72.30	3035.10	91.50	3352.00	2.03%	0.06%	2.03%	0.27%	PASS
28	73.00	3043.90	93.40	3362.00	69.20	3035.10	93.00	3354.00	5.21%	0.29%	0.43%	0.24%	PASS
29	72.30	3056.80	92.30	3352.00	68.80	3049.50	87.60	3373.00	4.84%	0.24%	5.09%	0.63%	PASS
30	82.30	3008.80	100.00	3356.00	71.50	3028.20	90.00	3365.00	13.12%	0.64%	10.00%	0.27%	FAIL
31	86.10	2982.70	102.30	3334.00	74.20	3003.30	93.40	3345.00	13.82%	0.69%	8.70%	0.33%	FAIL
32	74.60	3032.70	94.20	3365.00	70.00	3024.20	91.90	3357.00	6.17%	0.28%	2.44%	0.24%	PASS
33	94.20	2967.80	122.60	3326.00	72.30	3014.00	96.50	3349.00	23.25%	1.56%	21.29%	0.69%	FAIL
34	86.10	3009.30	103.80	3371.00	86.10	3009.30	103.80	3371.00	0.00%	0.00%	0.00%	0.00%	PASS
35	75.00	3066.00	96.50	3371.00	71.50	3048.60	92.60	3389.00	4.67%	0.57%	4.04%	0.53%	PASS
36	68.40	3056.10	96.10	3349.00	76.50	3028.10	106.10	3360.00	11.84%	0.92%	10.41%	0.33%	FAIL

Data and Results

Max. 24% Dc res had changed before and after the environmental test

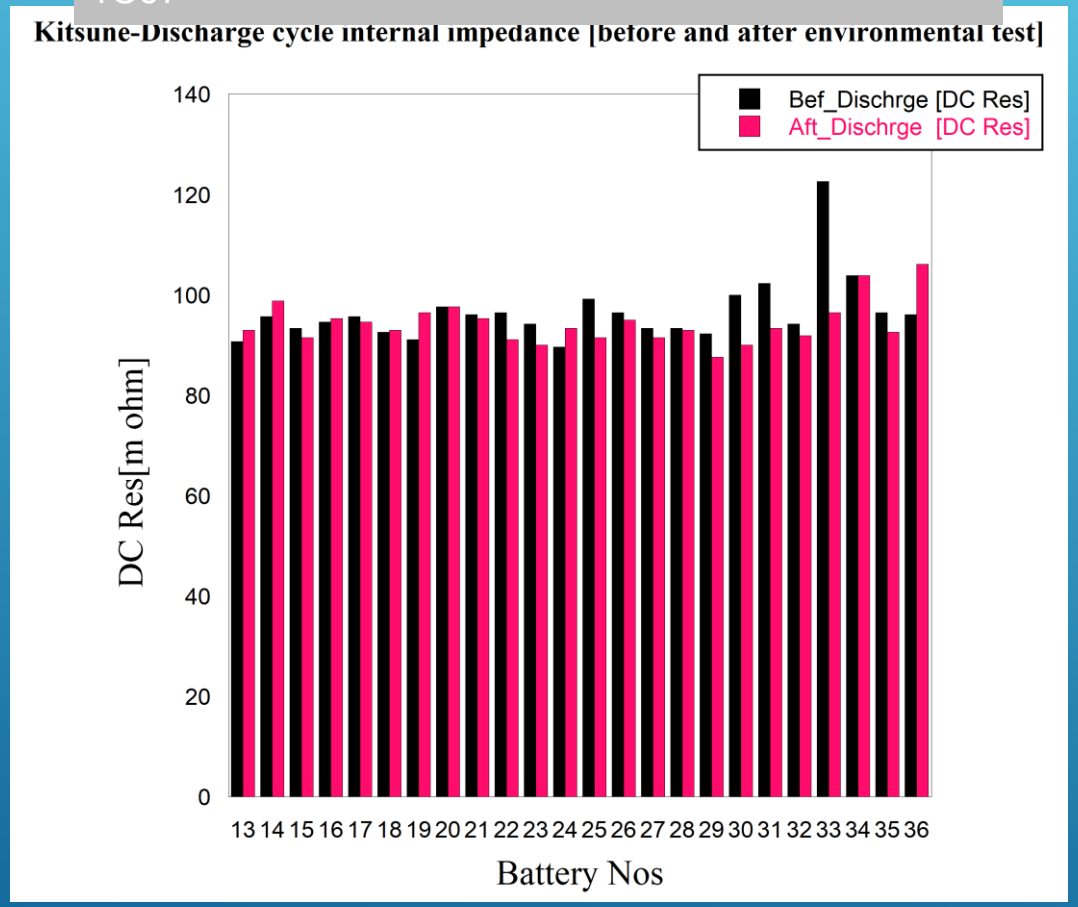


Fig: Result of Kitsune batteries discharge cycle DC Res[m ohm] _before and after environmental test

Max. 0.7% capacity had changed before and after the environmental test

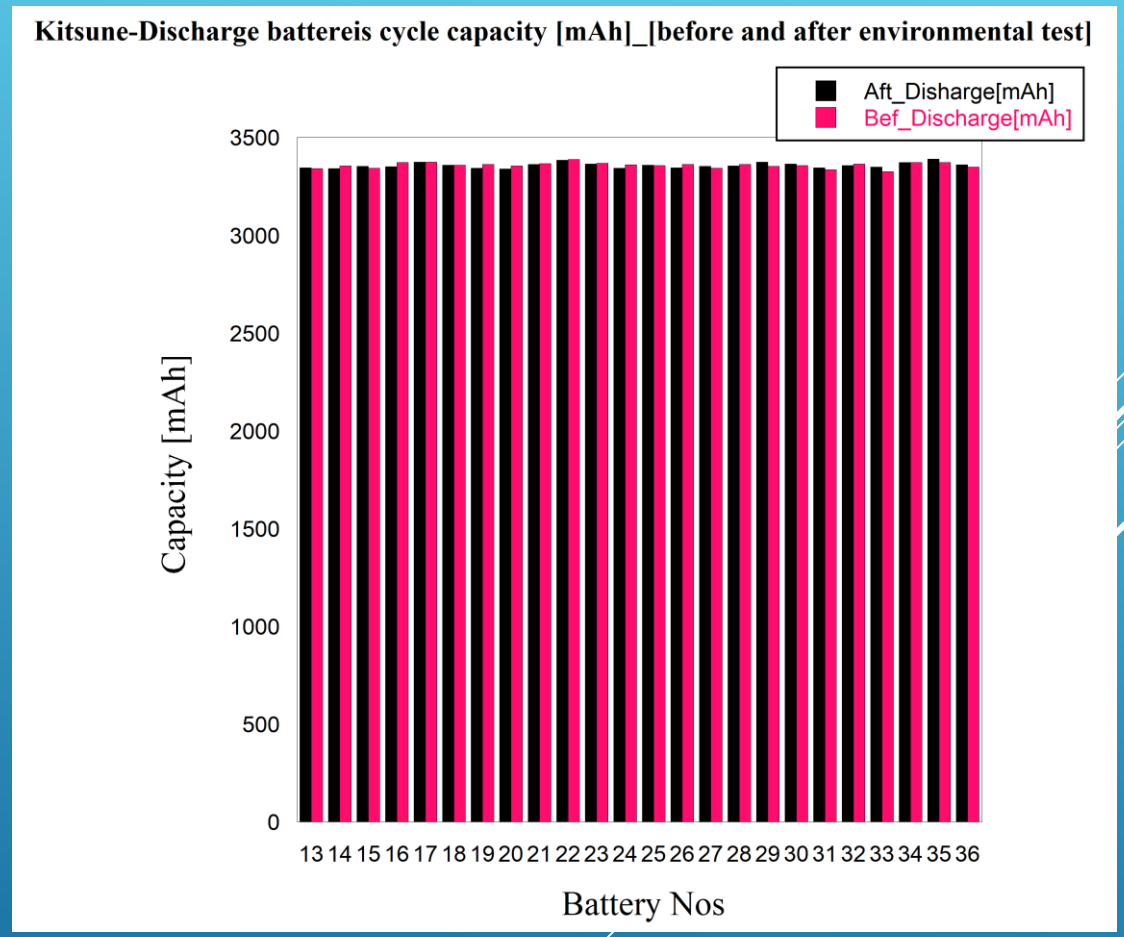
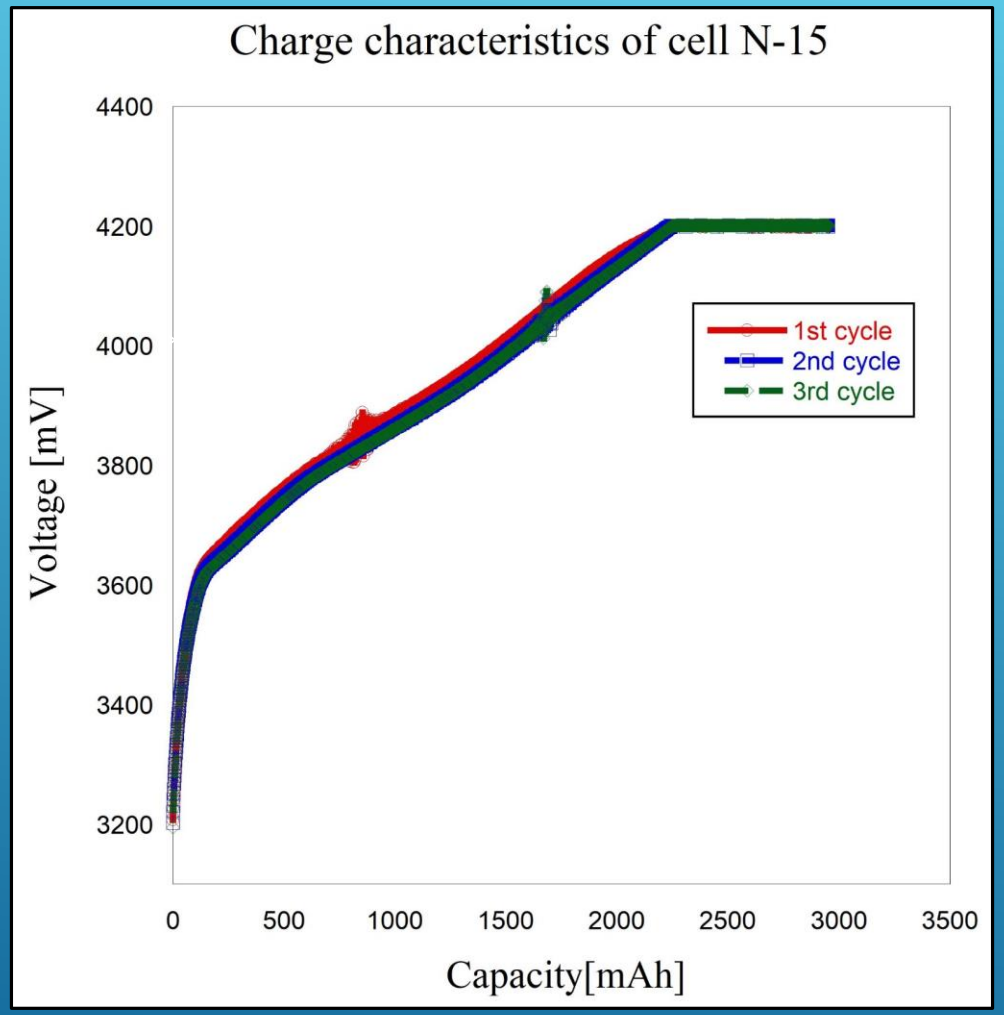


Fig: Comparison result of Kitsune batteries discharge cycle Capacity [mAh] _before and after environmental test

Charge and discharge- Kitsune



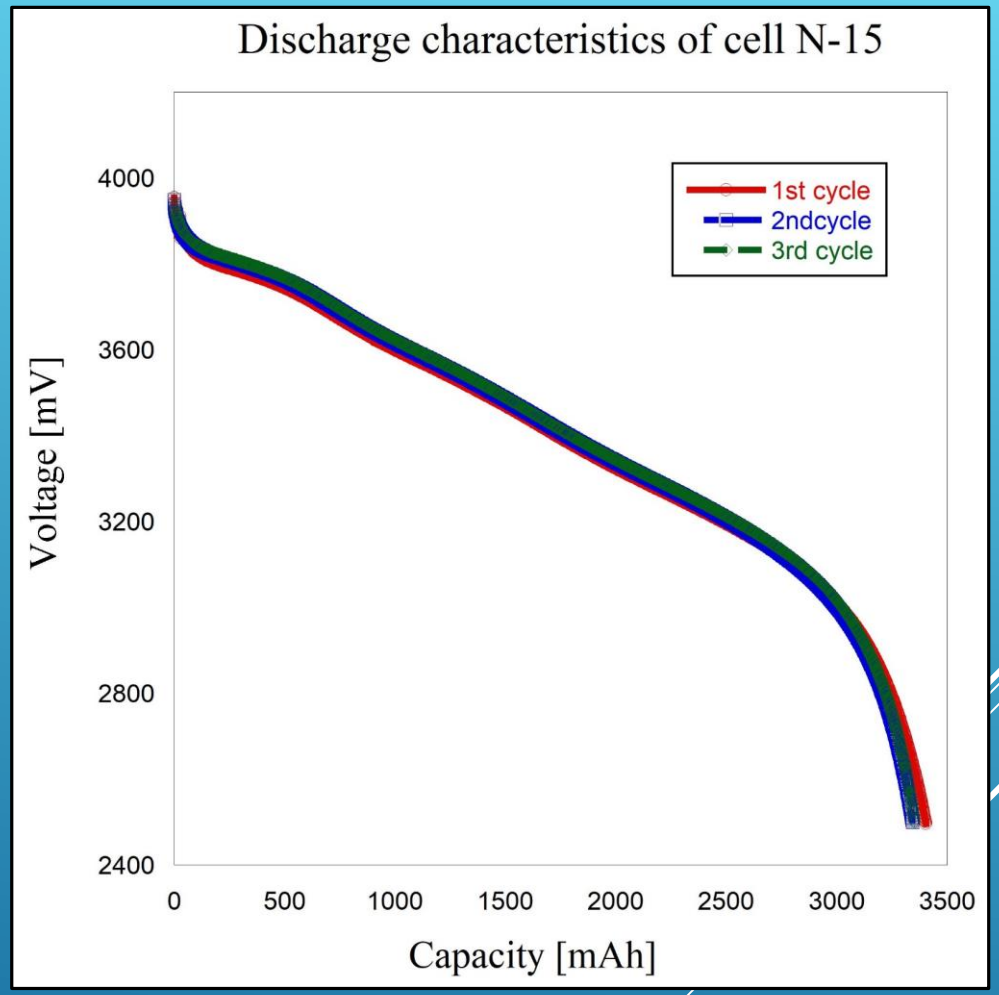


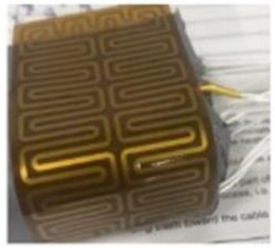
Fig: Kitsune FM battery's charge (left) and discharge (right) 3-cycles graph result [example battery no:15]

*Due to charger discharger system board noise shows the spikes during charge cycle

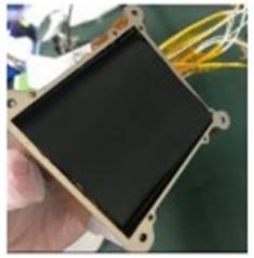
Battery assemble procedure-Kitsune satellite

STEP 1:
6 batteries are assembled. A thermistor is placed in-between.

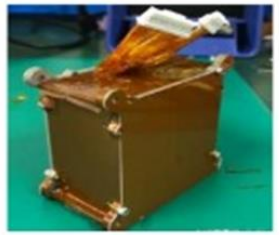
STEP 2: Batteries are then covered by lambda gel



STEP 3: Polymide heater is wrapped around the battery pack



STEP 4:
The battery pack is placed into the battery box covered with shrinkable tube



STEP 5: Battery cables are connected to the connectors and the battery box is closed

The assembled battery pack had an open circuit voltage of 7.46V

Fig:Assemble procedure steps

Fig: Battery layers with material

BATTERY TELEMETRY IN 2022

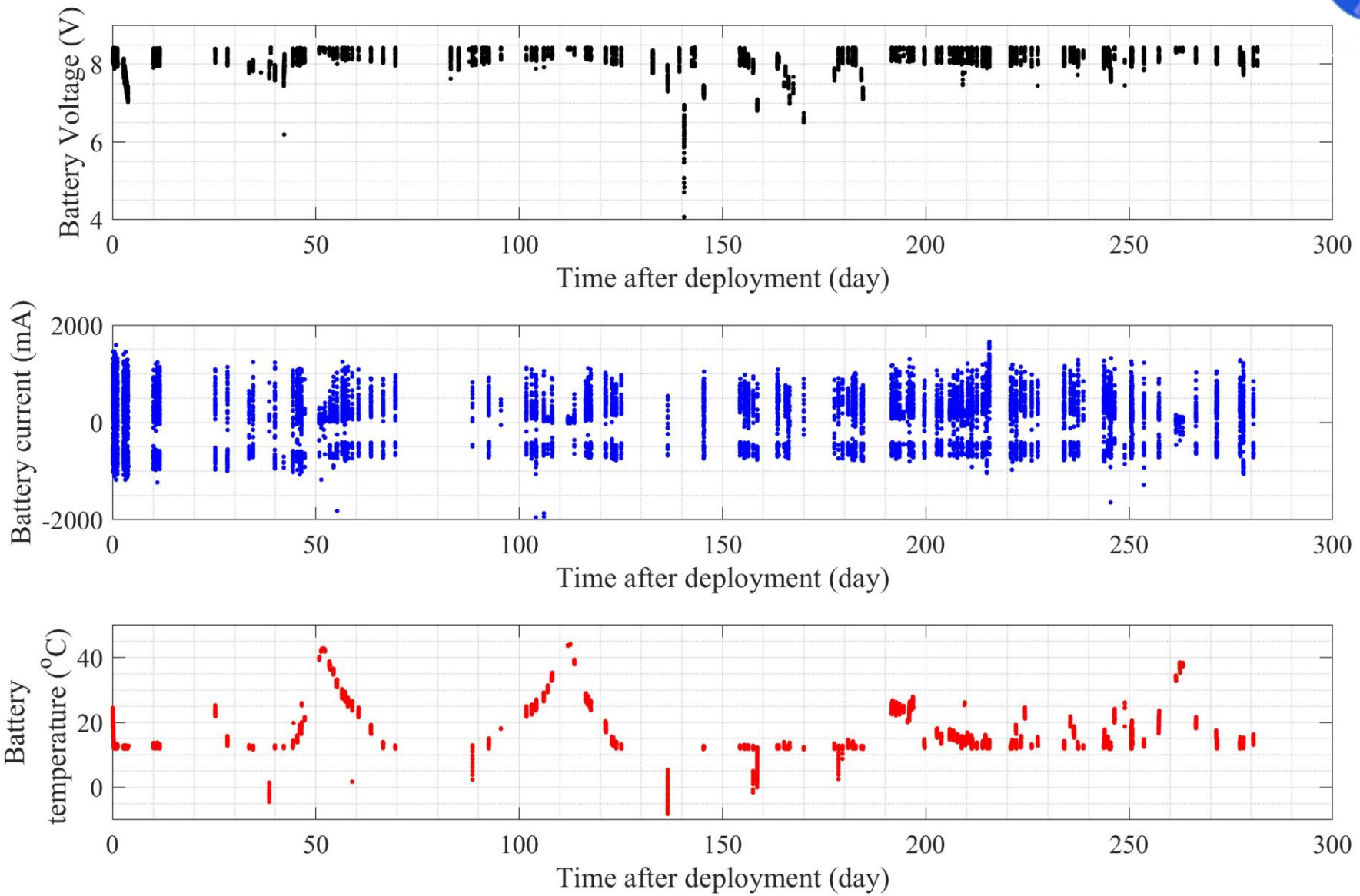


Fig: Kitsune satellite flight data of battery performance

Conclusion

For battery construction for space application,

- To select the closest characteristics value for Battery(cells) configuration, priority categories are DC_ resistance, Capacity, OCV and mass in sequence
- To perform the cells cycles test minimum three times including environmental test
- Assemble the properly the electrical and thermal insulator inside the battery box

	Cell#	OCV(<0.1%)	Mass(<0.5)	Capacity(<5%)	DC Resistance(< 10%)
Set A string	15	3.742	47.22	3352.00	91.50
	27	3.745	47.27	3352.00	91.50
Average		3.7435	47.245	3352.00	91.50
Standard Deviation		0.0021	0.0354	0.0000	0.0000
Deviation in percentage		0.06%	0.07%	0.00%	0.00%

Acknowledgements

- This project was supported in part by JSPS Core to Core program, B. Asia-Africa Science Platforms.

1.Dr.Rodrigo CORDOVA, 3U satellite project manager
2.Dr.Necmi CIHAN, KITSUNE project manager
3.Reynel Josue GALINDO ,D1 ,CURTIS team member
4.Dr.Yasir ABBAS, MO-1 satellite member
5.BIRDS satellite projects

Faculty of Engineering (school office and LASEINE family)

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