DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

ELECTRICAL POWER SYSTEMS FOR CUBESATS

GUIDED BY

Ms. DARSANA BABU

ASSISTANT PROFESSOR

DEPT. OF EEE

PRESENTED BY,

HARIKRISHNA PRAKASH

LKGR22EE019

Date: 22-08-2025

Table of contents

INTRODUCTION

- EPS (Electric Power Systems) manage power generation, storage, and distribution in satellites.
- EPS failure = mission failure.
- CubeSats are small, low-cost satellites with strict constraints (size, weight, environment).
- EPS must be efficient, compact, and fault-tolerant.

•Focus areas:

✓ Solar power (Triple-junction cells)
✓ Li-ion batteries
✓ Protection systems (Latch-up Current Limiter, Under Voltage Protection)
✓ Sizing & efficiency optimization

CLASSIFICATION OF SATELLITES

Type	Mass (kg)	Manufacturing time
Large Satellite	>1000	>5 years
Medium	500–1000	4 years
Mini	100–500	3 years
Micro	–100	1 year
Nano	1–10	<1 year
Pico	0.1–1	<1 year
Femto	<0.1	<1 year

Table 1:classification of different types of satellite


Fig1:Large type

RADARSAT-2

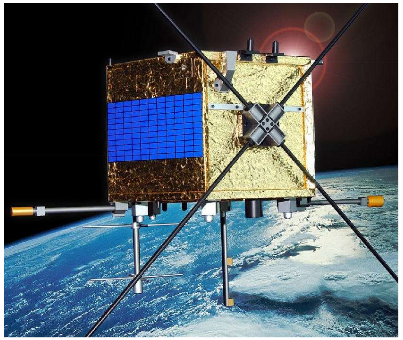


Fig2:Medium type

CASSIOPE

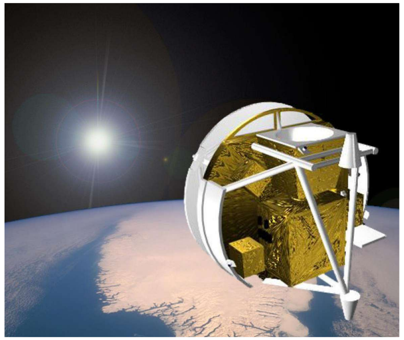


Fig3:Mini type

SCISAT 1

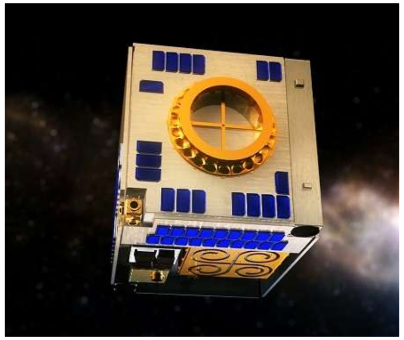


Fig4:Micro type

M3 MSAT


Fig5:Nano type

INSPIRESAT-1


Fig6:Pico types

STUDSAT

CubeSat Overview

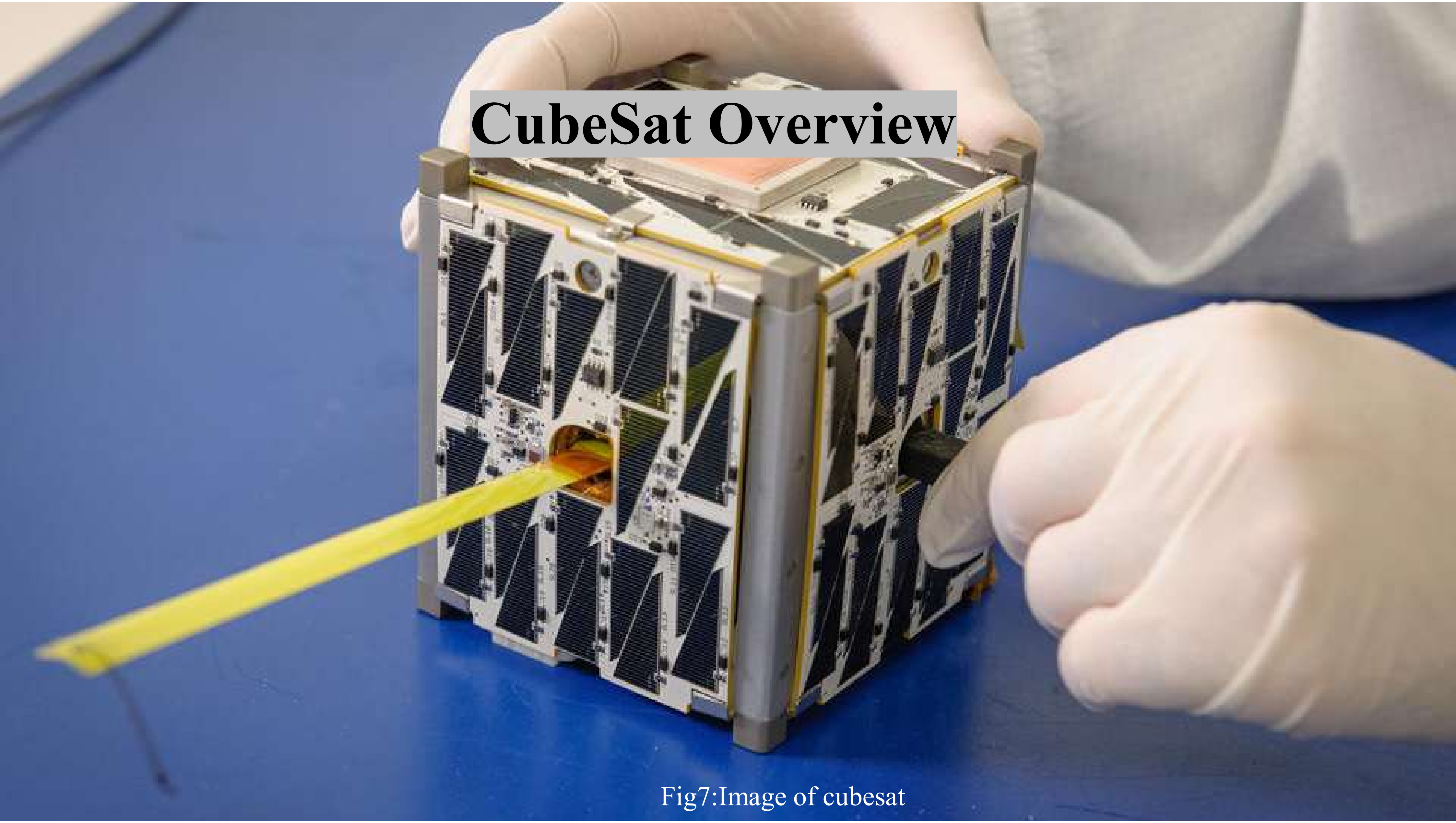


Fig7:Image of cubesat

CUBESAT OVERVIEW

01

Modular 10 cm × 10 cm × 10 cm units, ~1.33 kg each

02

Common builds: 1 U, 3 U, 6 U, 12 U configurations

03

Advantages vs large sats: lower cost, faster , simpler launch

04

Classified as nanosatellites (1–10 kg, < 1 year build

CUBESAT APPLICATIONS

- Space science & remote sensing
- High-speed Internet and communications
- Ship and aircraft tracking
- Planetary missions (e.g., Mars orbiters)

CUBESAT LAUNCH HISTORY

- - First launch: 2000 (two 1 U CubeSats tied together)
- - Slow growth until ~2013, then exponential rise
- - Forecast: > 500 nanosats/year by 2022
- - Drivers: miniaturization, lower launch costs

CUBESAT LAUNCH

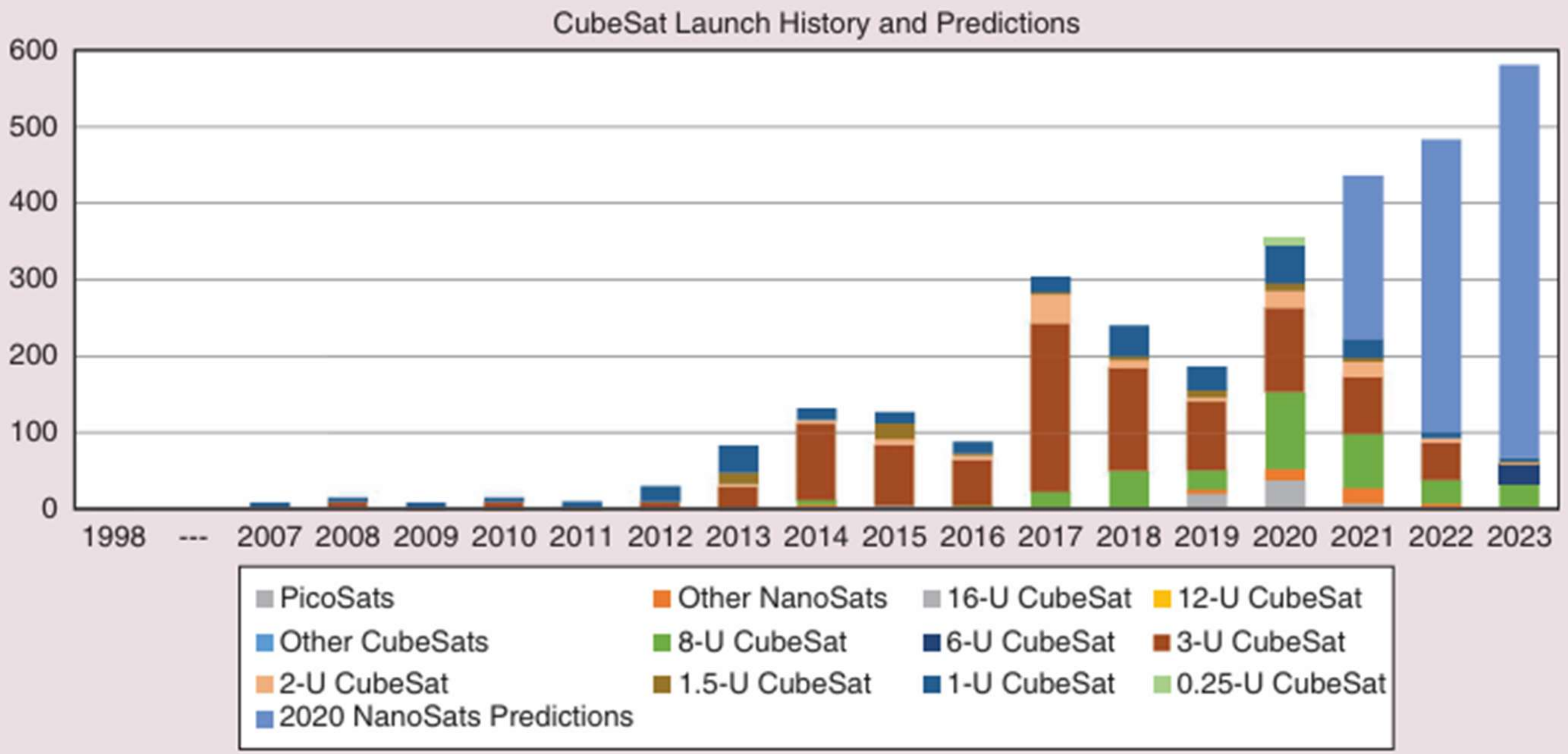


Fig8:graph image of cubesat launch history

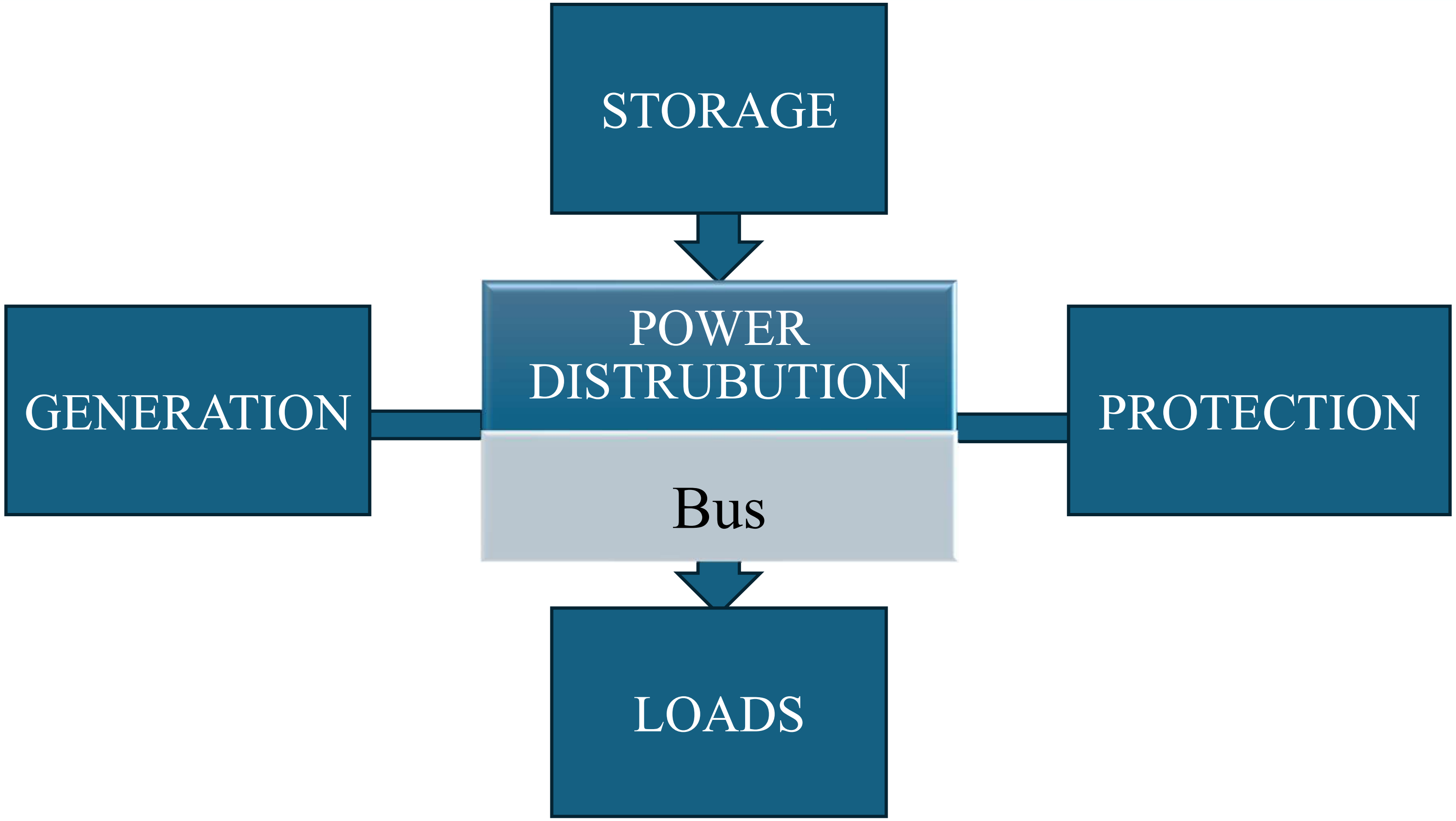
EPS ROLE IN CUBESATS

- Constraints: Mass, volume, radiation exposure, no on-orbit repair

- Must deliver high efficiency and fault tolerance

- Requires robust control methods for reliability

EPS FUNCTIONAL BLOCKS



EPS ARCHITECTURE IN CUBESATS

- **Generation:** PV solar arrays, MPPT, boost converters
- **Storage:** Battery strings, charge/discharge converters, thermal control
- **Distribution:** Main bus, load switches, regulators
- **Conditioning & Protection:** Latch-up limiters, UVP, kill switch

ENERGY GENERATION – PV CELLS

- Triple-junction GaInP/GaAs/Ge cells
- Higher efficiency & voltage than Si cells
- Use of concentrators to boost efficiency
- One-diode model for PV behavior

PV PERFORMANCE COMPARISON

Silicon (Si) Solar Cells

- Older, widely used in early space missions
- Lower efficiency
- Lower operating voltage

Triple-Junction (TJ) GaInP/GaAs/Ge Solar Cells

- Advanced multi junction technology
- Higher energy conversion efficiency
- Operates at higher voltage — suitable for space power systems

PERFORMANCE PARAMETERS COMPARED

PARAMETER	Si Cell	GaInP/GaAs/Ge Cell
OPEN CIRCUIT VOLTAGE	Lower	Higher
SHORT CIRCUIT CURRENT DENSITY	Moderate	High
EFFICIENCY (%)	~15–18%	~28–30%

Table 2:Comparison of si cell and GaInP/GaAs/Ge Cell

MPPT AND POWER CONTROL

- MPPT is essential for efficient power extraction in space
- Combined with a boost converter, it maximizes power flow to batteries and loads
- CubeSat power systems depend on MPPT to ensure mission reliability

MPPT AND POWER CONTROL

GOMspace NanoPower P31u EPS:

8 solar input channels, each with built-in MPPT

Real-time adjustment for highest energy harvesting

Integrated into many commercial CubeSats

Fig 9:Image of GOMspaceP31U

PV MODELING, PANELS & POWER PROFILE IN CUBESATS

1. PV Power Modelling

- Output power of a PV cell:

$$PV = Ps \times \frac{\eta su}{PV \cdot KG \cdot KT \cdot KR}$$

- Where:
- *Ps*= Solar power incident on panel
- *ηsun/PV*= Cell efficiency
- *KG*= Irradiance factor
- *KT*= Temperature factor →

$KT=1+\alpha(Ti-T_{AM0})$

- *KR*= Reflection loss

PV MODELING, PANELS & POWER PROFILE IN CUBESATS

2. CubeSat PV Panels

- Example: GOM space P110 Panel
  - ✓Up to 30% efficiency
  - ✓Operates from −40°C to +80°C
  - ✓Compact, rugged for LEO missions

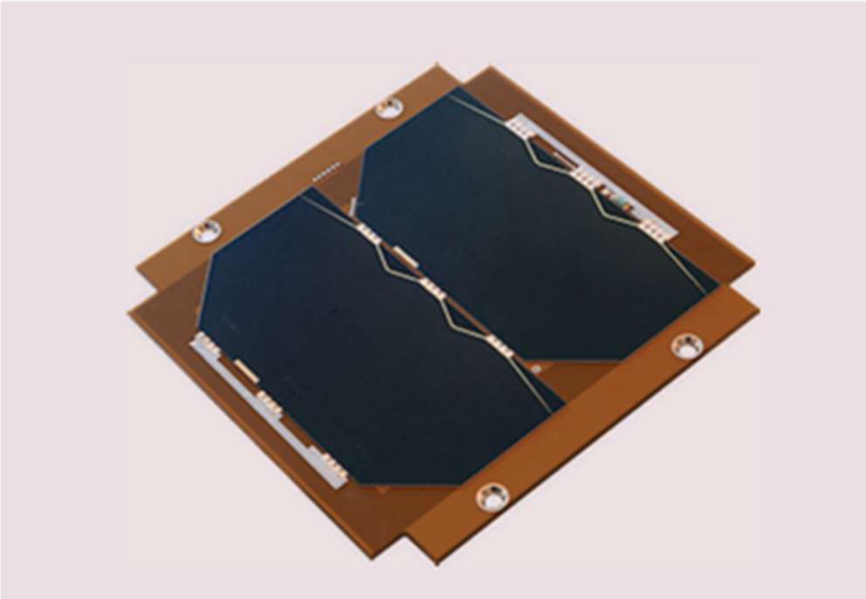


Fig 10:Image of GOM space P110 Panel

ENERGY STORAGE – BATTERY TECHNOLOGIES

3. PV Power Profile Over Orbit

Sunlight: PV powers loads + charges battery

Eclipse: PV = 0; battery powers all systems

Temperature near Sun ↑ Efficiency ↓

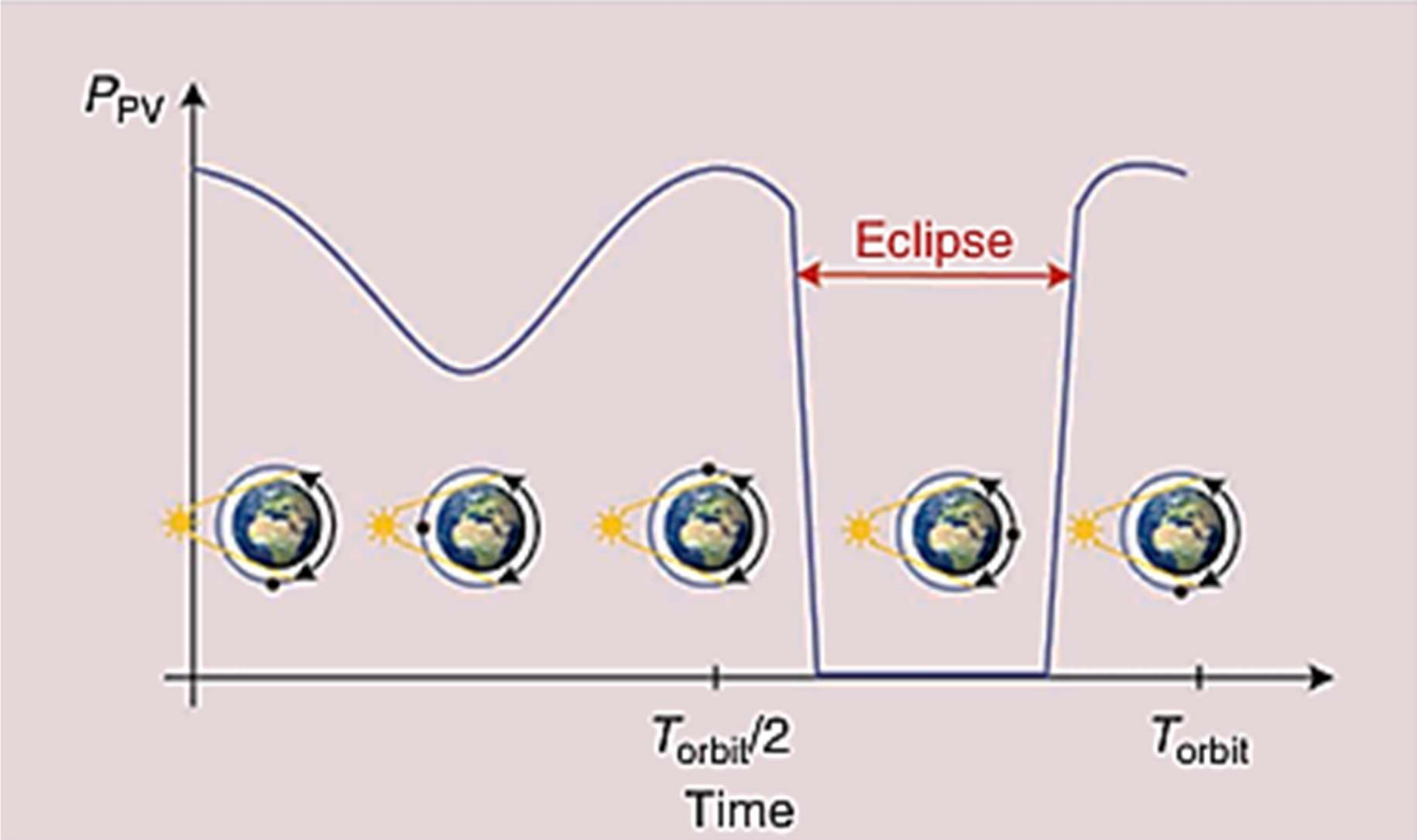


Fig 12:Image of PV power profile during one orbit.

BATTERY CAPACITY, DOD & CHARGE/DISCHARGE BEHAVIOR IN CUBESATS

1. Battery Capacity & Energy

- Capacity (C) = total charge battery can deliver

  Unit: Ah (ampere-hour)
- Energy (Wh) = Capacity × Nominal Voltage

$$E = C \times V_{nom}$$

- CubeSats typically use Li-ion batteries for high energy density

BATTERY CAPACITY, DOD & CHARGE/DISCHARGE BEHAVIOR IN CUBESATS

2. Depth of Discharge (DoD)

- DoD = % of battery's capacity used per cycle

$$DoD = \frac{C\ used}{C\ total}$$

- Lower DoD → Longer battery life
- Typical DoD range: 30–50%
- High DoD or full discharges reduce lifespan quickly

BATTERY CHARGE/DISCHARGE PROFILE

Charging phase	Random positive current (depends on surplus PV power) ▪ Once EOCV (end-of-charge voltage) is reached → switch to voltage mode ▪ Battery still draws small current to compensate internal losses
Discharging phase	Supplies current during eclipse or peak loads ▪ Discharges until end-of-discharge voltage ▪ Controlled to avoid deep discharge

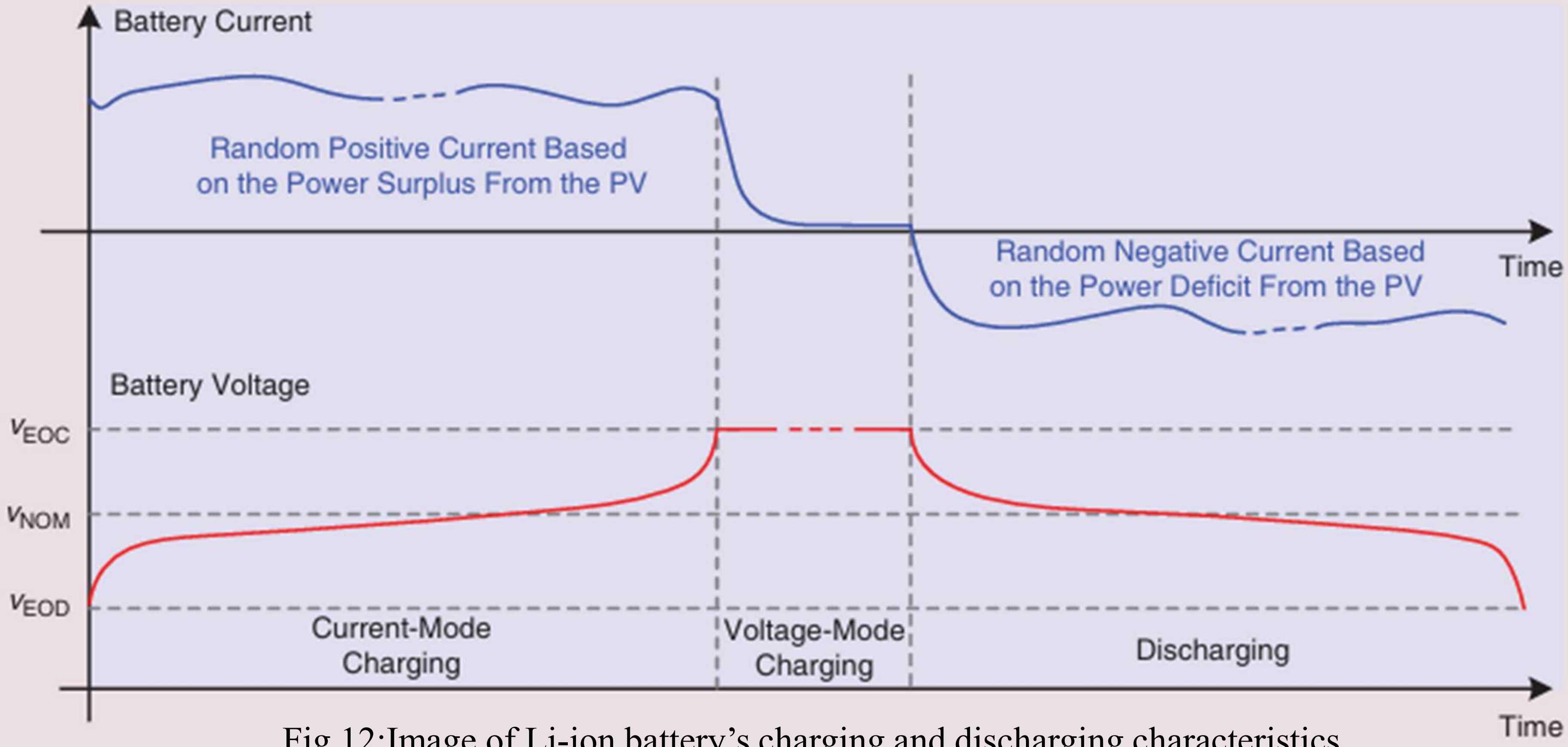


Fig 12:Image of Li-ion battery's charging and discharging characteristics.

BATTERY THERMAL MANAGEMENT IN CUBESATS

- Li-ion batteries are highly sensitive to temperature.
- Space environment = extreme cold and hot conditions.
- Performance degrades in both cases:
  - ✓ Cold = ↑ Internal resistance - ↓ Output power
  - ✓ Hot = ↑ Chemical degradation - ↓ Battery life

BATTERY THERMAL MANAGEMENT IN CUBESATS

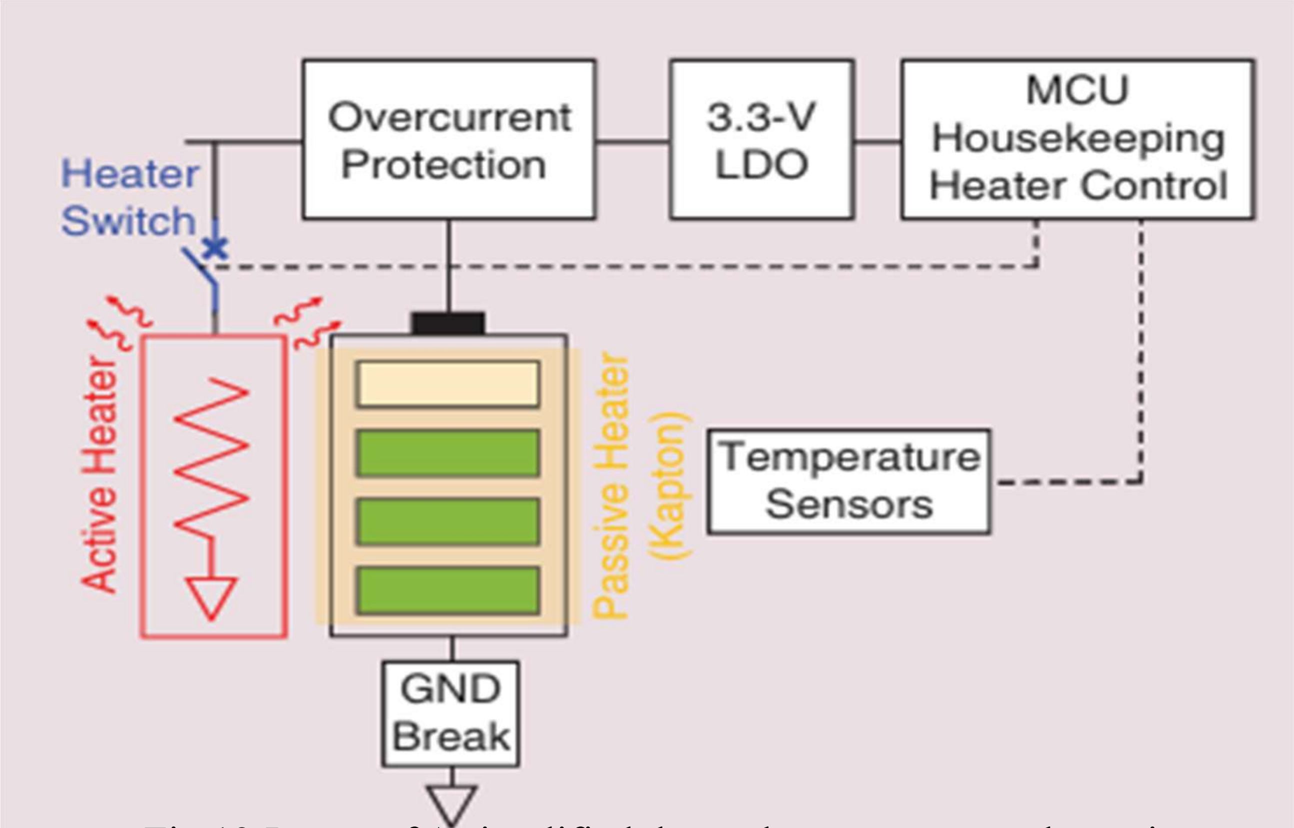


Fig 13:Image of A simplified thermal management schematic

BATTERY THERMAL MANAGEMENT IN CUBESATS

- Uses resistor-based electric heaters
- Powered by the battery itself
- Activates only when needed, saving energy
- Temperature sensors monitor battery heat
- Microcontroller Unit (MCU) controls the heater switch
- Powered via 3.3 V LDO regulator
- Includes overcurrent protection to avoid fault

EPS PROTECTION SCHEMES

- Latch-Up Current Limiter (LCL)
- Under voltage Protection (UVP)
- Prevents damage from faults/overloads

LATCH-UP CURRENT LIMITER (LCL) & UNDERVOLTAGE PROTECTION (UVP)

1. Latch-Up Current Limiter (LCL)

- Protects EPS from overcurrent conditions
- Triggered when load current exceeds safe limit
- Responds by:
  - ✓Entering current-limiting mode
  - ✓Starting a trip-off timer
  - ✓If fault continues → load disconnected

LATCH-UP CURRENT LIMITER (LCL) & UNDERVOLTAGE PROTECTION (UVP)

2. Undervoltage Protection (UVP)

- Ensures system shuts down safely during voltage drops
- Triggered when bus voltage < defined threshold
- Uses hysteresis to avoid repeated ON/OFF from noise
- Distributed: Each LCL has its own UVP
- Centralized: One UVP controls all loads
- Needs single-point failure protection

SIZING OF BATTERY AND SOLAR ARRAY IN CUBESAT EPS

1. Battery Sizing

- Voltage Selection: $V\ Bus = NS \times V\ cell$
- Capacity (Ah): $C = \frac{E\ Battery}{Vbus}$
- Depth of Discharge (DoD): $DoD = \frac{E\ eclipse}{E\ battery}$
- (Limit DoD to ~30–50% for long life)

SIZING OF BATTERY AND SOLAR ARRAY IN CUBESAT EPS

- Total Energy Required:

$$EPV \geq Eload+Ebattery+Elosses$$

CHALLENGES & FUTURE DIRECTIONS

- Miniaturization vs. radiation hardness
- Advanced converters: soft-switching, GaN/SiC
- Novel storage: solid-state, supercap hybrids
- AI-driven health monitoring & adaptive control

CONCLUSIONS

- This presentation explores modern EPS concepts specifically for CubeSats, including:

✓ Power generation using high-efficiency triple-junction solar cells

✓ Energy storage through compact and reliable lithium-ion batteries

✓ Power management and protection, such as MPPT, LCL, and UVP

✓ Thermal control strategies for battery reliability

✓ Sizing methods for solar arrays and batteries to match mission demands

REFERENCES

[1] A. Lashab, D. Sera, and J. M. Guerrero, “Dual-input quasi-Z-source PV inverter: Dynamic modeling, design, and control,” IEEE Trans. Ind. Electron., vol. 67, no. 8, pp. 6483–6493, Aug. 2020.

[2] M. E. Robles, J. A. Martinez, and P. D. Cortez, “Design and optimization of a modular electrical power system architecture for CubeSats,” in Proc. 2021 IEEE Aerospace Conf., Big Sky, MT, USA, Mar. 2021, pp. 1–8.

[3] S. Bajaj and A. Rao, “High-efficiency MPPT converter for CubeSat solar arrays,” in Proc. 2021 IEEE Int. Conf. Power Electron., Drives Energy Syst. (PEDES), Chennai, India, Dec. 2021, pp. 1–6.

[4] R. W. Healy, S. McClean, and M. Sakr, “Reliability analysis of lithium-ion battery systems for CubeSat EPS,” IEEE Trans. Reliab., vol. 71, no. 2, pp. 342–351, Jun. 2022.

THANK YOU