# DESIGN CONSIDERATIONS FOR AEROSPACE BATTERY MANAGEMENT SYSTEMS

PRESENTERS
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**4 MARCH 2024**

# AGENDA

- Introduction
- Battery Pack Architecture & Protections
- Li-ion Cells & Heater
- Power Optimization - Electronics Selection & Storage Life
- Test & Verification
- Summary

# INVENTUS POWER OVERVIEW

## GLOBAL MANUFACTURING & DESIGN RESOURCES

**9** countries

**4** continents

**3K** employees

**300+** engineers

## VERTICALLY INTEGRATED

engineering & agency approvals

## INNOVATIVE SOLUTIONS

for range of markets & applications

## PROVEN SAFETY & RELIABILITY

**~60 years** industry experience

**2K+** programs launched

**1B+** products safely delivered

# INVENTUS POWER OVERVIEW

## GLOBAL LEADER IN ADVANCED BATTERY SYSTEMS

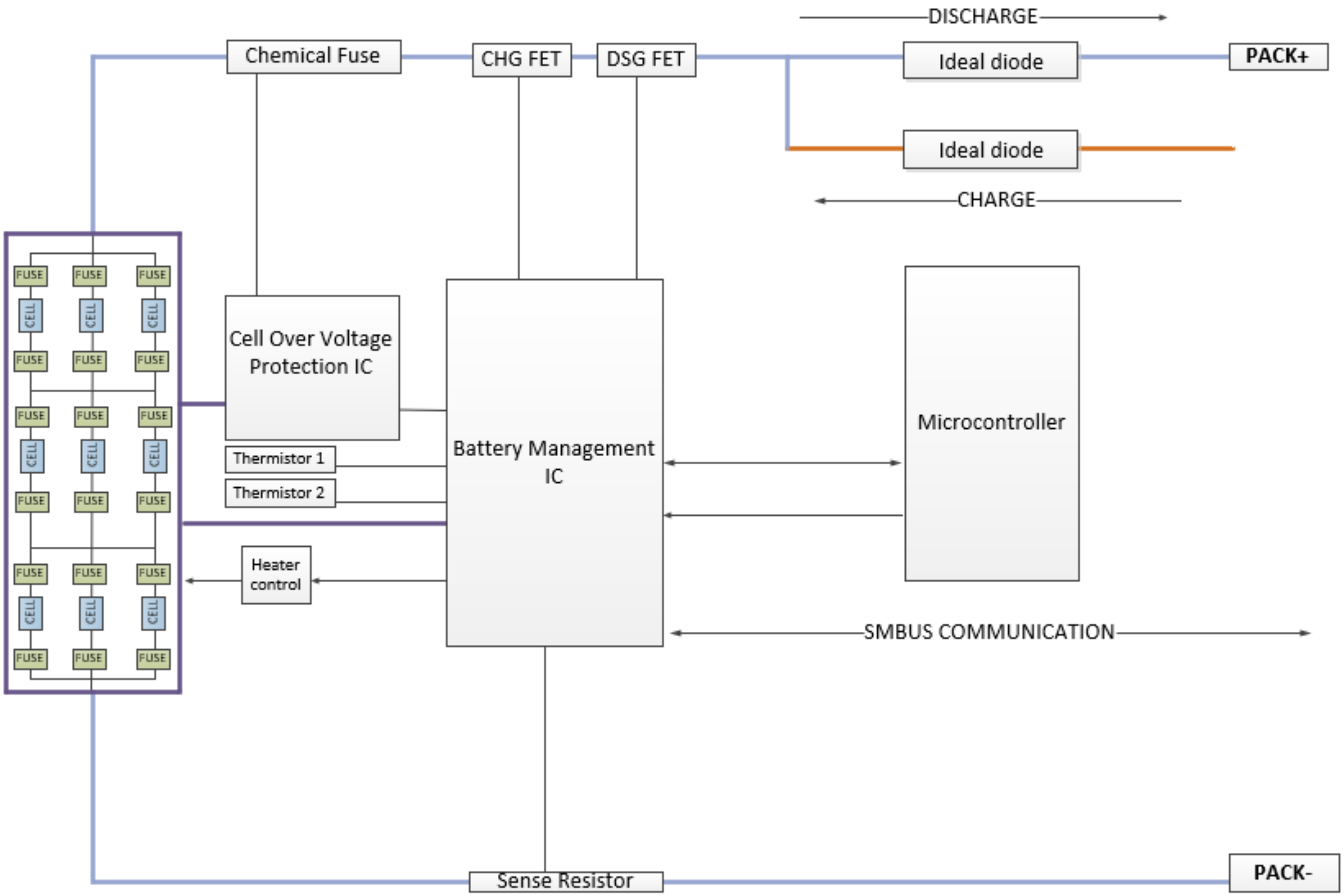
- Design & manufacture Li-ion battery solutions for military, medical, commercial & industrial markets
- Specialize in unique battery management system (BMS) solutions
- Global engineering & operations with US location focused on complex military & medical applications
  - Conformable Wearable Battery (CWB)
    - Worn directly by warfighter
    - Conformable to human body
    - High capacity (10.3Ah)
    - Small Form (8.6” x 7.6”)
    - Ruggedized  temperature, shock & atmospheric operation

# DESIGN SCOPE

- Discussions limited to the application environment being Stratosphere (10-50km above Earth's surface):
- Temperature range: -60 to 0°C, Low pressure ($10^{-3}$ atm), Low levels of radiation (UV)
- Lithium-ion cells are considered for the application – mainly because of their high energy density and our expertise using them for similar applications
- Leveraging of design experience in MIL-STD testing and verification.

# ARCHITECTURE & PROTECTIONS

# ARCHITECTURE



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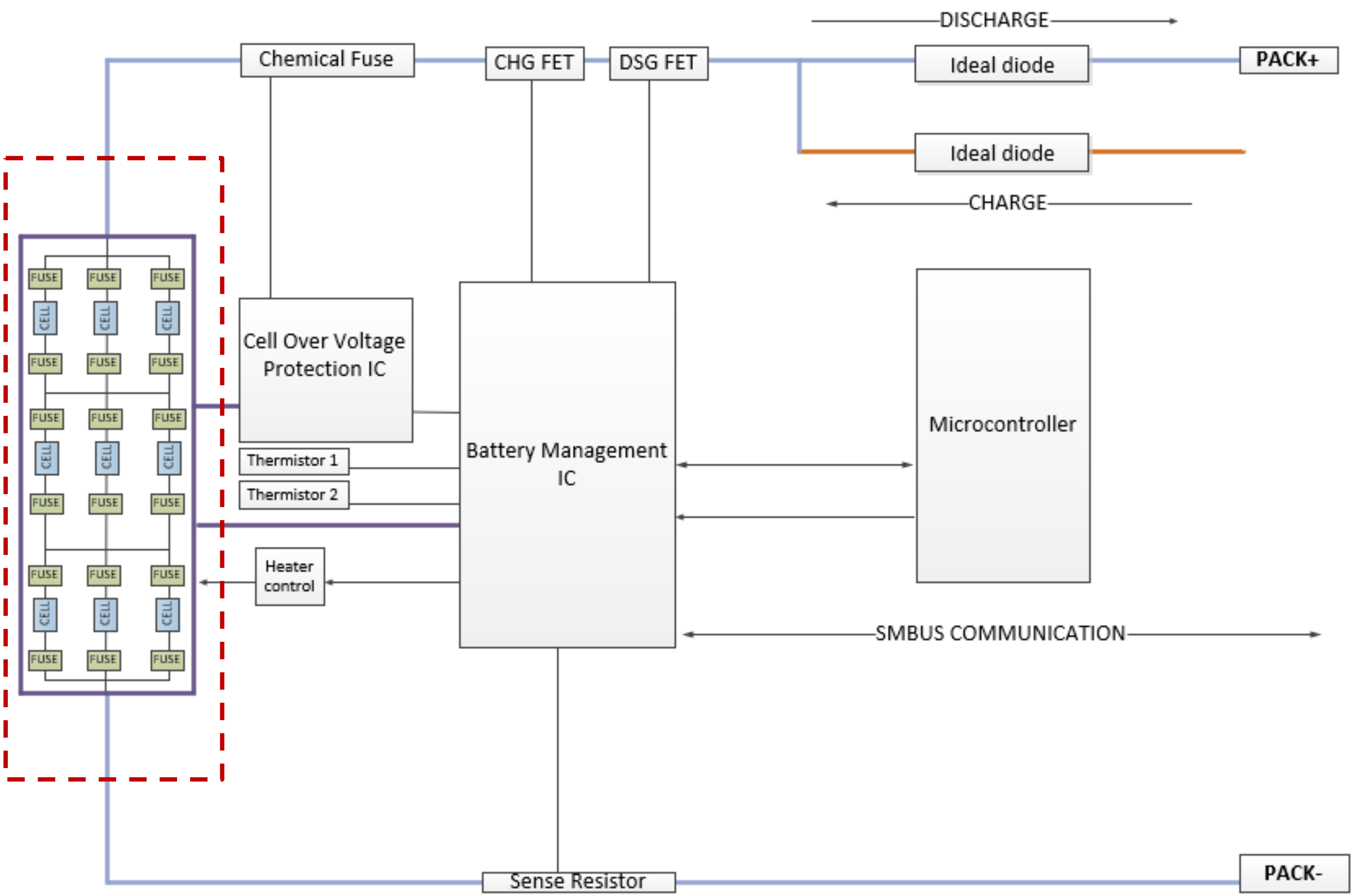

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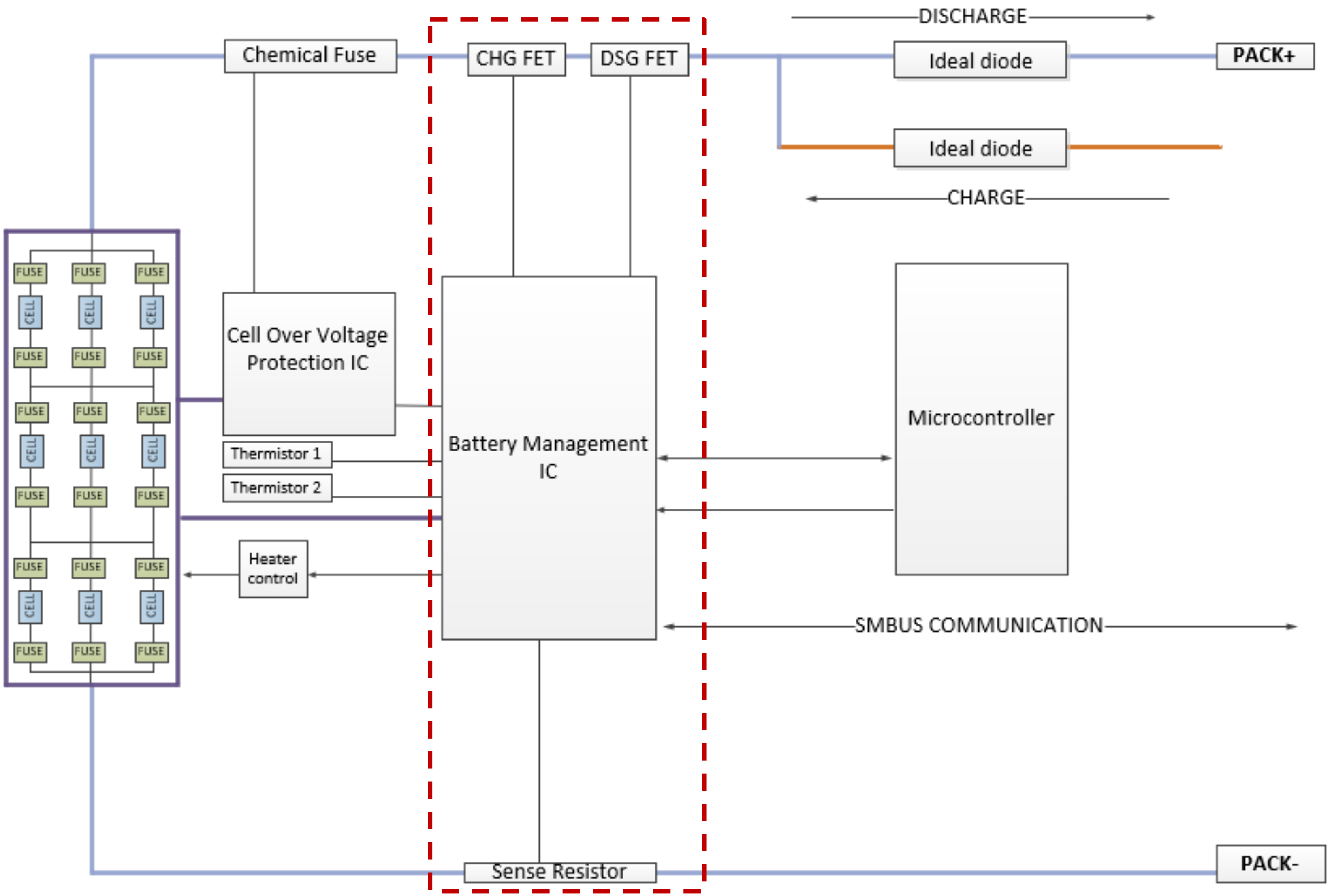

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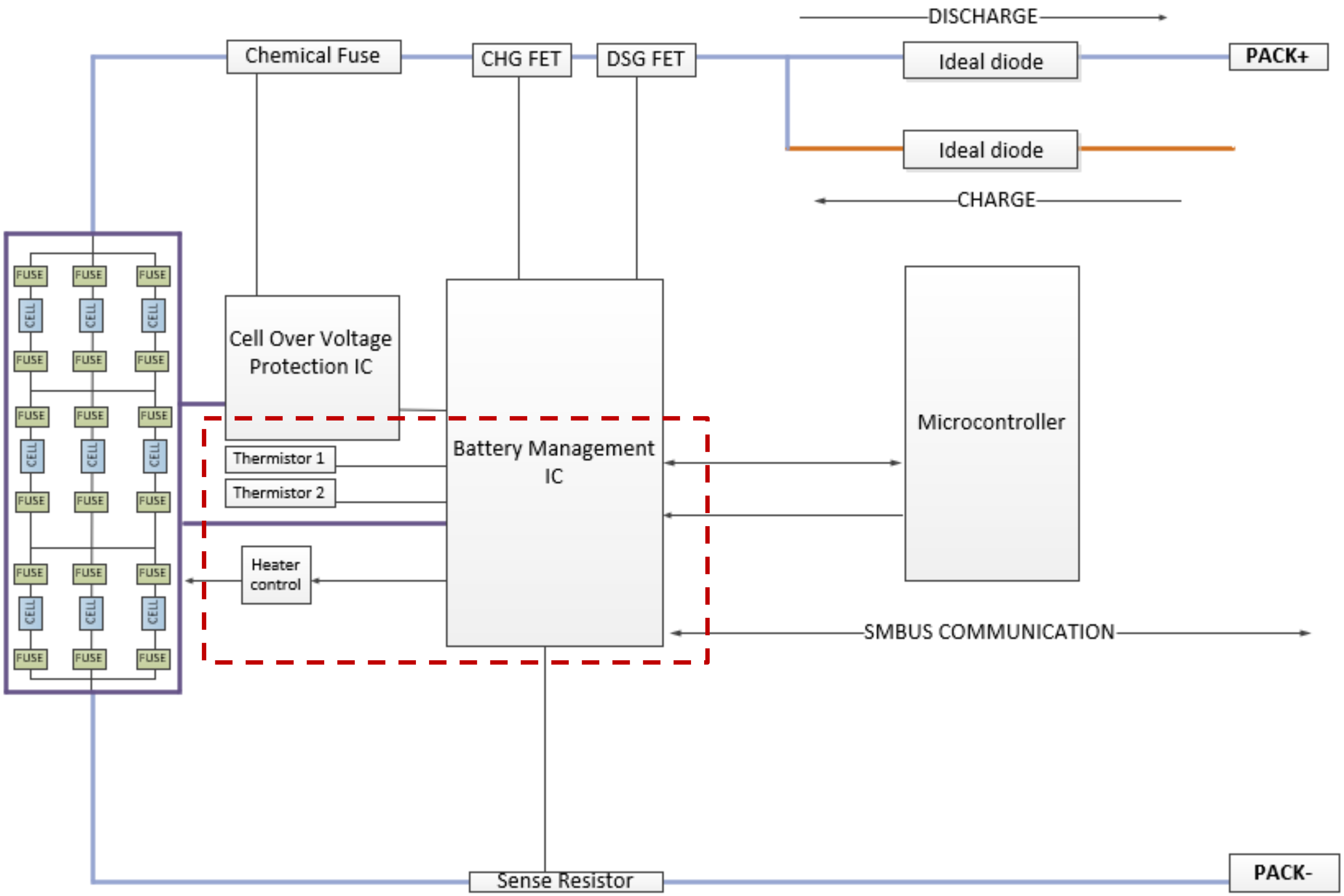

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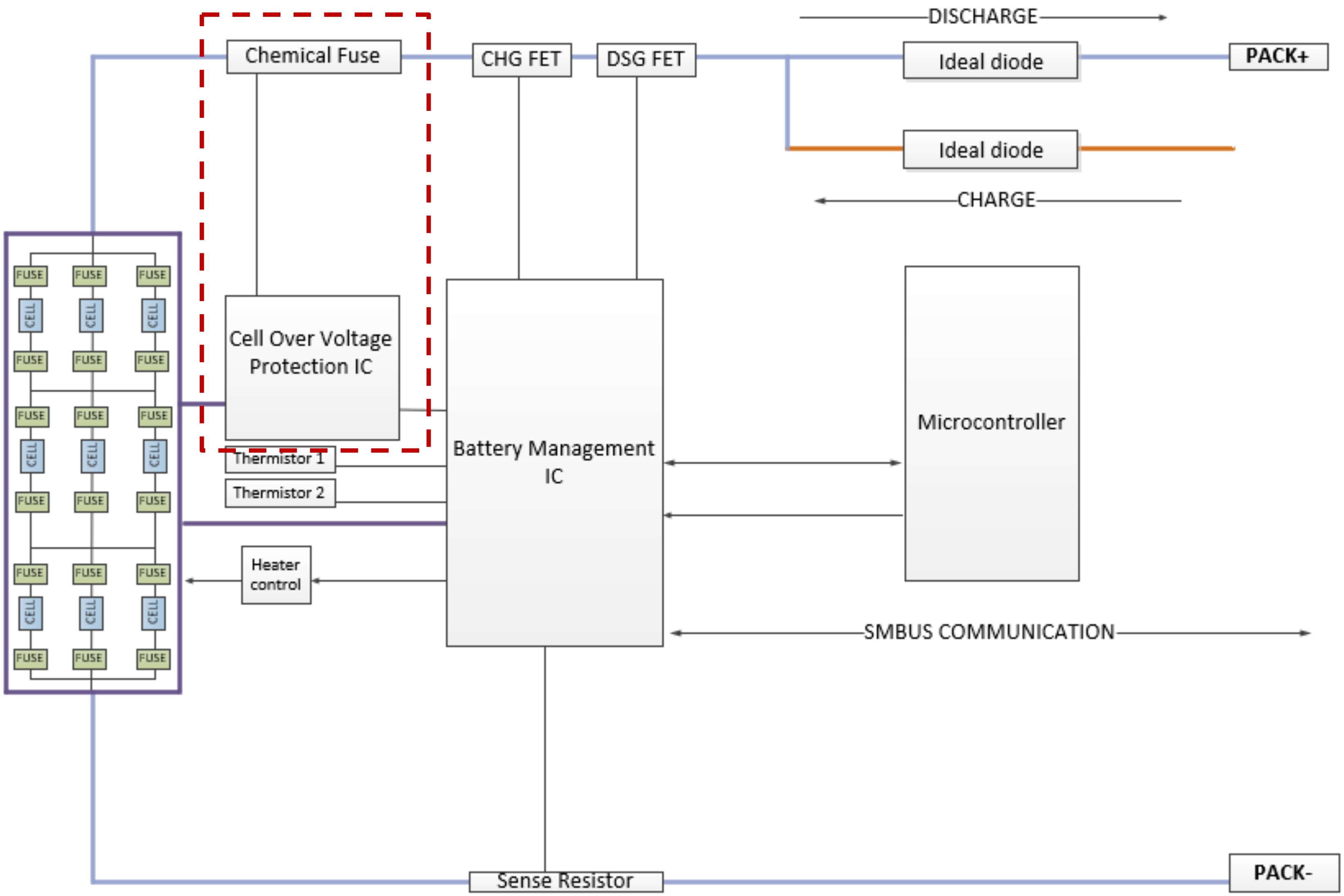

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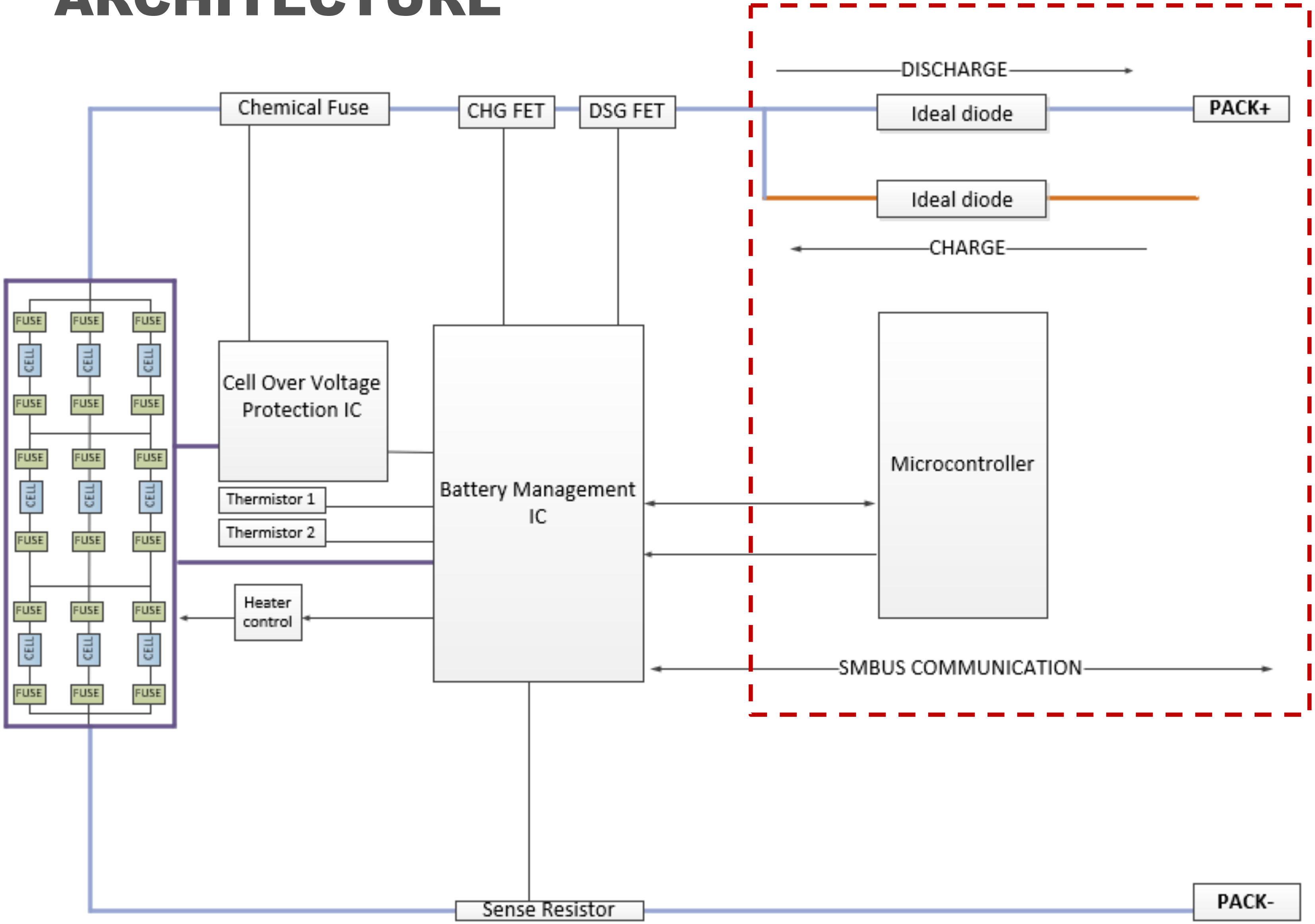


# PROTECTIONS & COMMUNICATIONS

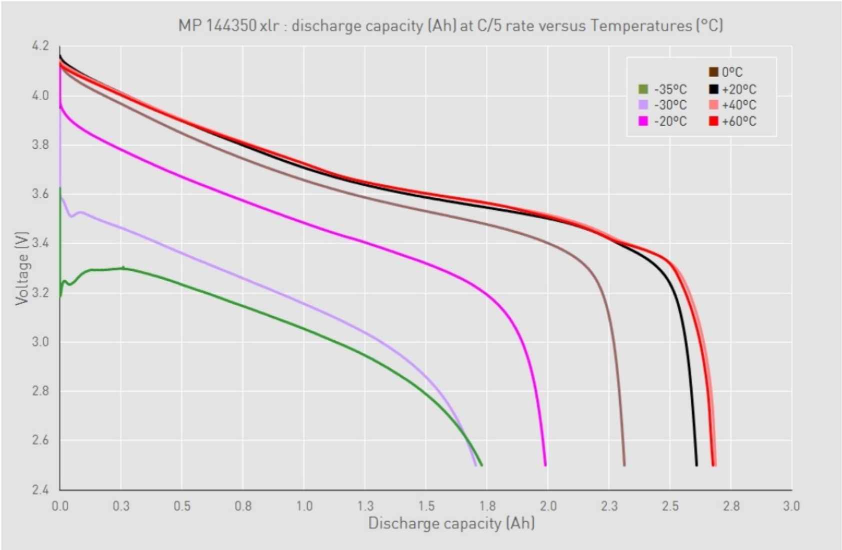
- The architecture provides the below protections at multiple levels:
  - Cell over and under voltage
  - Cell over current and short circuit
  - Cell over temperature

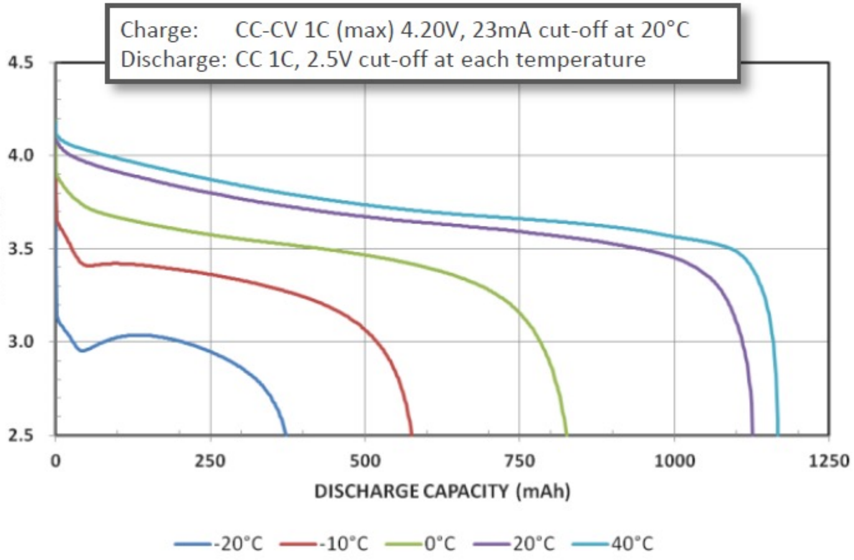
- Understand trade-offs between protecting the pack & continuing to power the application device
  - If the application device has redundant battery packs, protections can be active
  - Otherwise, having a bypass switch to continue powering the application even at faulty conditions is desirable
  - Battery pack can communicate the faulty conditions to application device and the device can take steps to safely shutdown

# LI-ION CELLS & HEATER

# LI-ION CELLS

- Li-ion cells work differently in different temperatures, with comfortable operating range being -20°C to 60°C
- At cold temperatures, discharge current and capacity of cells degrade
- Select cell that can function in the temperature range of application (-60°C to 0°C), if not add heater
- Comparison between SAFT MP144350 and Panasonic UF553450Z



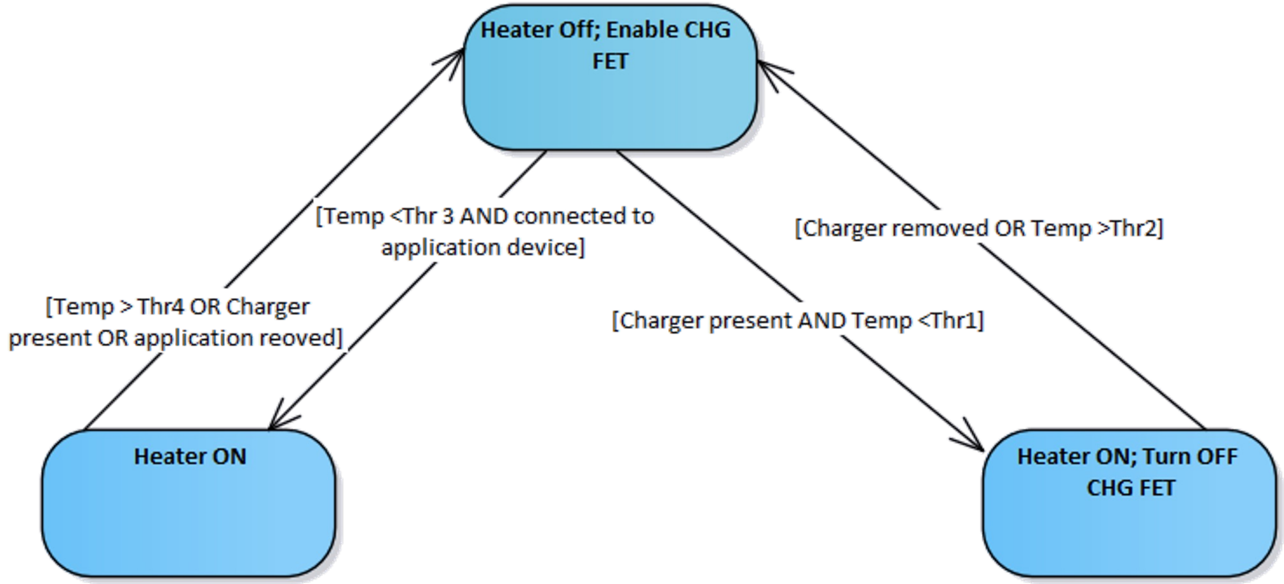



# HEATER

- Utilize temperature sensors, placed at multiple positions in pack to measure cell temperature
- Range of temperatures for charge/discharge of cells available in datasheet
- Different types of heaters are available such as trace heating and heater pads.

# HEATER STATE MACHINE

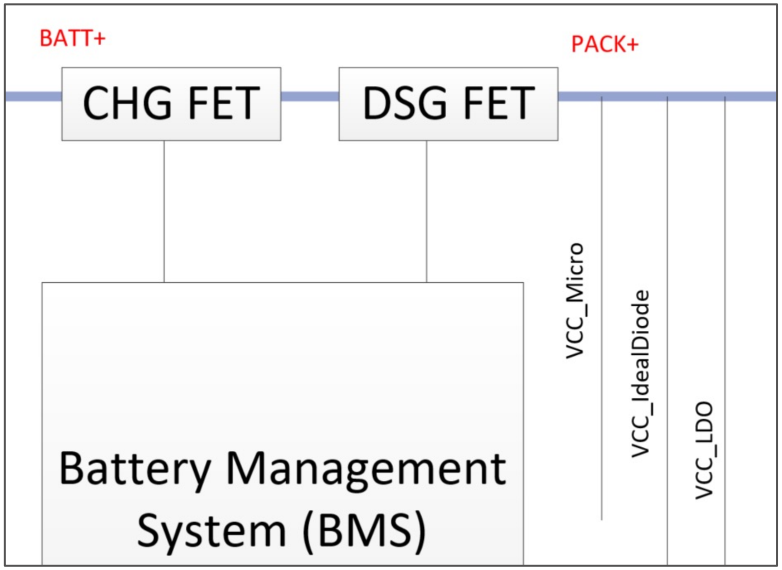
- Thr1: Minimum cell temperature to charge safely
- Thr2: Safe cell temperature to turn off heater while charging
- Thr3: Minimum cell temperature to discharge safely
- Thr4: Safe cell temperature to turn off heater while charging



# POWER OPTIMIZATION

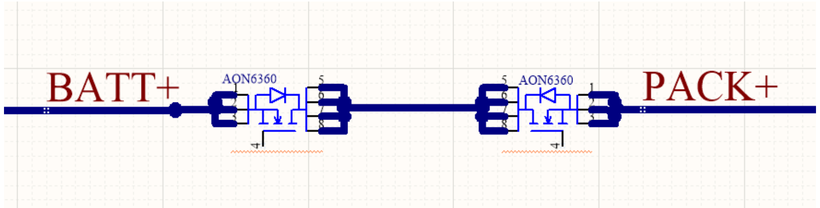
# POWER OPTIMIZATION TECHNIQUES

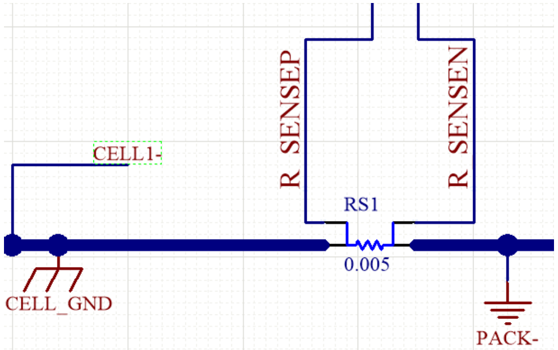
- Heater Circuit
  - Cells lose charge capacity as a result of ambient temperature <0°C
  - Pre-charge of heater circuit allows cell to heat > 23°C before charge cycle
- CWB Battery Pack - Operation Modes
  - Active ( >7mA)
  - Sleep ( > 2mA)
  - Shutdown (10 ~ 30$\mu$A)
- Low Quiescent Electronic Design
  - Cascading Vcc lines after CHG, DSG FET

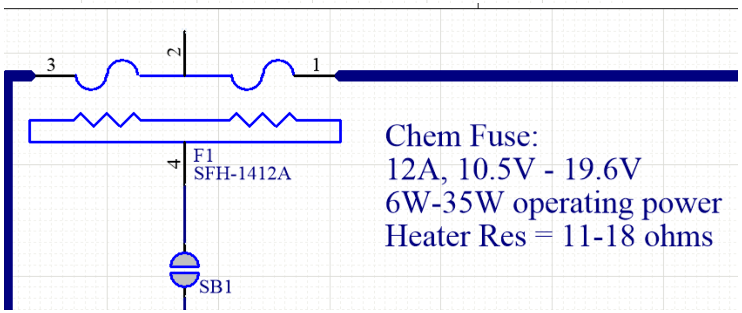


# POWER PATH OPTIMIZATION

- Power MOSFETs
  - Low $R_{DS_{on}} \sim mOhm$ , low $V_{TH}$
  - GaN technologies smaller and lower losses
- Sense Resistor
  - Low $R_{Sense} \sim mOhm$ , Kelvin Connection
- Fuse / PTC
  - Low $R_{Sense} \sim mOhm$, 100% derating,
  - Smaller footprint ~ smaller $R_{fuse}$



# ELECTRONICS SELECTION

- Commercial IC selection susceptible to latch-up, upset, gate rupture, extreme temperature failures.
- Selection of components for optimization (in order of importance)
  - Low quiescent power consumption, radiation hardness assurance (RHA), low voltage drop, small footprint

| Category | Component | Company | Part | TID Rad. Assurance |
|---|---|---|---|---|
| Power Management | Low drop-out reg. (LDO) | TI | TPS7A4501-SP | 100krad |
| Battery Management | BMS (2-7Series) | TI | bq40z80 | n/a |
| Power Management | DC/DC converter | TI | TPS50601A | 100krad |
| Active | Power MOSFET | Infineon | BUY06CS45B-01 | 100krad |
| Microprocessor | ULA16-bit microcontroller | TI | MSP430FR5969-SP | 50krad |

# STORAGE LIFE ANALYSIS

- Battery packs stored in idle "sleep" mode aboard vehicle; woken up upon use
- Pack life
- Cell self-discharge rate
- Quiescent current draw of PACK+ and BATT+
- Cascading component placement

- Battery Management System modes
  - Sleep
  - Shutdown
  - Active
- Resulting sleep storage life

| | Month | | | | | |
|---|---|---|---|---|---|---|
| Storage - @ Initial State of Charge Defined Above | 0 | 1 | 2 | 60 | 72 | 84 |
| Total Consumed Capacity (Typ) | 0 | 28.38144 | 56.76288 | 1702.8864 | 2043.46368 | 2384.04096 |
| Total Consumed Capacity (From Minimum) | 0 | 28.008 | 56.016 | 1680.48 | 2016.576 | 2352.672 |
| Remaining Capacity (typ) | 2512.5 | 2484.11856 | 2455.73712 | 809.6136 | 469.03632 | 128.45904 |
| Remaining Capacity (min cell start) | 2437.5 | 2409.492 | 2381.484 | 757.02 | 420.924 | 84.828 |
| ASOC (from typ cell) | 25.77% | 25.48% | 25.19% | 8.30% | 4.81% | 1.32% |
| ASOC (from min cell) | 25.00% | 24.71% | 24.43% | 7.76% | 4.32% | 0.87% |

# TEST & VERIFICATION

# PACK & CELL QUALIFICATION

## Cell Qualification

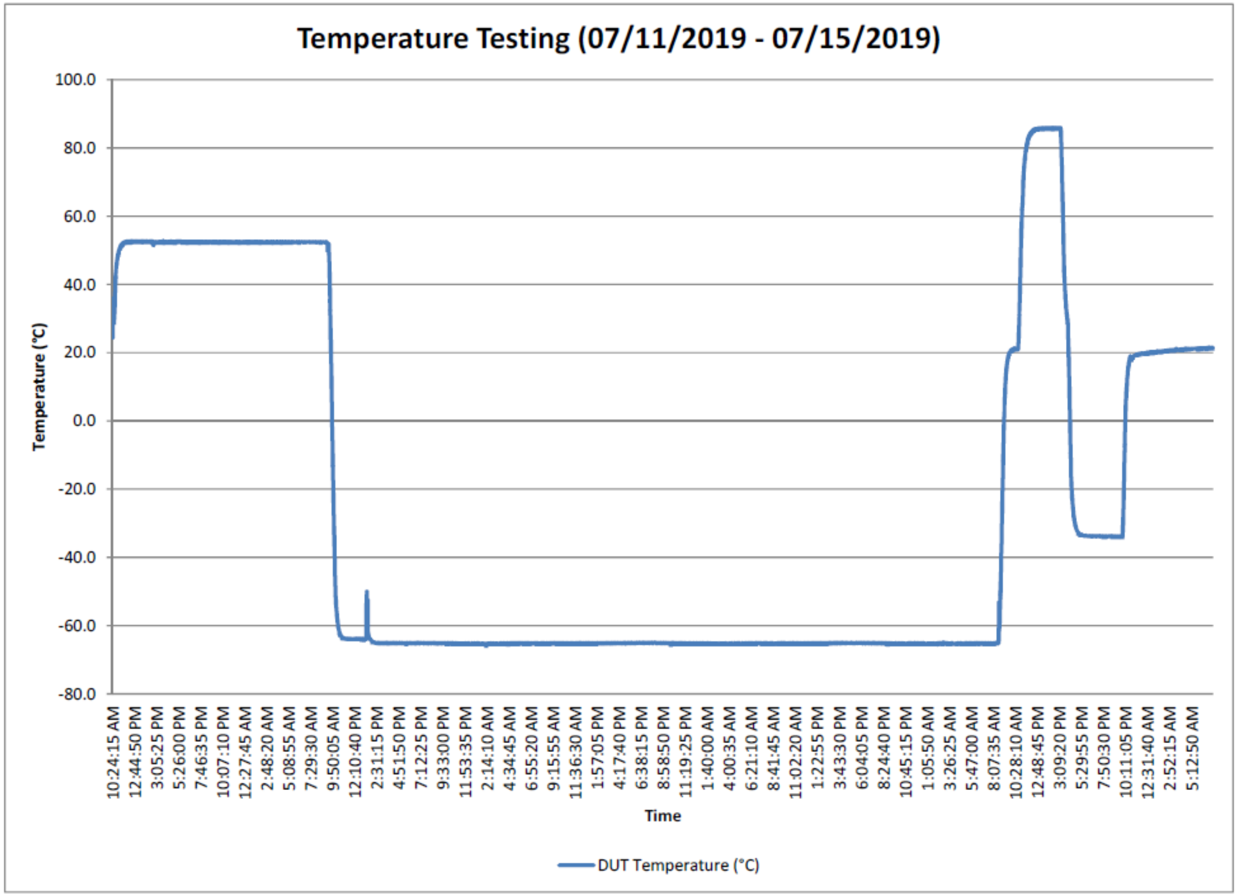
| | | |
|---|---|---|
| Cell Impedance | Overcharge | Impact |
| Nail Penetration | Life Cycle | High Rate |
| OCV Table Test | Accelerated Storage | Altitude |
| Vibration | Hot Box | Low Temp/High Temp |

## Pack Qualification

| Function Verification Test | | Reliability Test | |
|---|---|---|---|
| 1. Software logic verification test | 10. Pins FMEA test | 1. Higher temperature storage test | 10. Altitude test |
| 2. DVT test for adapter | 11. Communication test | 2. Lower temperature storage test | 11. Insertion test |
| 3. Compliance table test | 12. V-I Curve test | 3. Temperature shock test | 12. Immersion test |
| 4. Component Thermal test for low/medium/high temperature | 13. Cycle life test | 4. Vibration test (810G) | 13. **IPXY test**: X:0~4,Y:0~3 |
| 5. Function cycles test for low/medium/high temperature | 14. Operate temperature range test | 5. Shock test (810G) | 14. HALT test |
| 6. System application test | | 6. Humidity test | |
| 7. Output Short Test | | 7. ISTA 1A/2A/3A test | |
| 8. Fuel Gauge test | | 8. Flex test | |
| 9. Cold start test | | 9. Drop test | |

# TEMPERATURE

- Temperature Range : -65°C to 85°C




Temperature Testing Chart (DUT Temperature)

# EXPLOSIVE ATMOSPHERE

- Test to Demonstrate:
  - Ability of material to operate in fuel-air explosive atmospheres without causing ignition
  - Explosive or burning reaction occurring within encased material will be contained and will not propagate outside the test item

# SUMMARY

Architecture with redundant protections at multiple levels ensures battery pack is safe to operate in environment

Utilize heaters to maintain cell temperature at recommended range during charge & discharge is critical

Optimizing power with electronic component selection, placement & various modes of operation provides long storage life & minimizes power loss

RHA and aerospace-grade components ensure system reliability, safety & traceability

Thorough test & verification in aerospace conditions at both cell & pack level ensure functionality

Inventus Power battery packs (i.e. CWB) have been tested under harsh atmospheric conditions are a strong base to modify for aerospace applications

# THANK YOU!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