1. Introduction

Monitoring lithium-ion batteries is crucial for **safety, efficiency, and longevity**. The system must track:

1. **Pack voltage** (total voltage across all cells)
2. **Pack current** (charging and discharging)
3. **Individual cell voltages**

The system uses a **3S Li-ion pack** (3 cells in series) with only **one Pack+ and Pack- terminal**, requiring a solution that **does not need access to each cell's terminals for current measurement**.

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2. Objectives

- Measure **total pack voltage** accurately.
- Measure **pack current** during **charging and discharging**.
- Measure **individual cell voltages** to detect imbalance.
- Use **minimal hardware**, compatible with a **single Pack+ / Pack- terminal**.
- Provide data to **ESP32** for monitoring, logging, and control.

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3. System Components

Component	Purpose
ESP32	MCU to read sensors, process data, and communicate results
INA226 module	High-side shunt current sensor to measure pack current & voltage
ADS1115 module	16-bit ADC for high-resolution individual cell voltage measurements
Shunt resistor	Included with INA226 for current measurement (0.1–0.5 mΩ typical)
Jumper wires	Connect battery, sensors, and MCU

Resistors (optional)	Voltage dividers for ADC if needed
Charger	3S Li-ion battery charger
Load	Device powered by battery pack
Pull-up resistors 4.7kΩ (optional)	For I²C SDA/SCL lines if not present on modules

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4. System Design

4.1 Battery Configuration

- **3S Li-ion pack**: 3 cells in series (nominal 11.1V, max 12.6V).
- Terminals available: **Pack+** and **Pack-** only.
- All cells in series share the **same current**, so **individual cell current measurement is unnecessary**.

4.2 Pack Current & Voltage Measurement (INA226)

- **Placement:** High-side (between Pack+ and charger/load).
- **Function:**
    - Measures **current direction** (charging/discharging).
    - Measures **pack voltage**.

Wiring:

```
Charger + ----+
              \
              [Shunt] ----> INA226 VIN+ --> VIN- ----> Pack+
              /
             Load
Pack - --------------------------------> ESP32 GND / common ground
```

- **Bidirectional current sensing:** Negative → charging, Positive → discharging
- **Shunt resistor:** Included with INA226 module

4.3 Individual Cell Voltage Measurement (ADS1115)

- **Differential measurement** for accuracy: measures **voltage across each cell** using **one ADS1115 module**.
- **Channel mapping:**

Cell	ADS1115 Pins	Connections
Cell1	A0+ / A0-	A0+ → Cell1+ , A0- → Pack-
Cell2	A1+ / A1-	A1+ → Cell2+ , A1- → Cell1+
Cell3	A2+ / A2-	A2+ → Cell3+ , A2- → Cell2+
Pack Voltage (optional)	A3+ / A3-	A3+ → Cell3+ , A3- → Pack-

- **Ground:** ADS1115 GND → Pack-
- **I²C communication:** SDA/SCL → ESP32

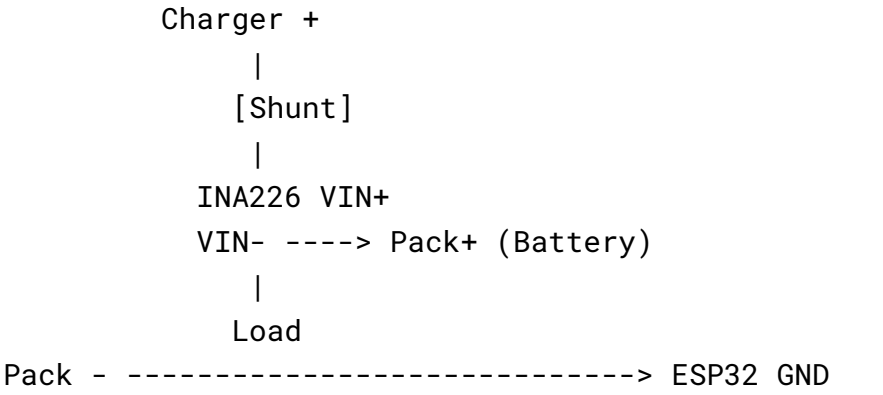
4.4 ESP32 Integration

- Reads **INA226** and **ADS1115** via I²C.
- Calculates:
    - Individual cell voltages
    - Pack voltage (sum of cell voltages or INA226 bus voltage)
    - Charge/discharge current
    - Cell imbalance (max voltage – min voltage)

ESP32 Pin Example:

Function	Pin
I²C SDA	GPIO21
I²C SCL	GPIO22
GND	Pack- / sensor GND
3.3V	Power sensors

5. System Wiring Overview




```
ADS1115 Differential Inputs:
  Cell1: A0+ → Cell1+ , A0- → Pack-
  Cell2: A1+ → Cell2+ , A1- → Cell1+
  Cell3: A2+ → Cell3+ , A2- → Cell2+
  Optional Pack Voltage: A3+ → Cell3+, A3- → Pack-
```

Notes:

- Only **one Pack+ / Pack-** required
- Current is measured **through a single INA226 shunt**
- Individual cell currents are **not measured** (all series cells share the same current)

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6. System Operation

1. **Charging:**
    - Current flows into the battery → INA226 shows negative current
    - ADS1115 measures each cell voltage → ESP32 detects any overvoltage
2. **Discharging:**
    - Current flows out → INA226 shows positive current
    - Cell voltages monitored for under-voltage
3. **Cell Imbalance Detection:**
    - ESP32 calculates **Max Cell Voltage – Min Cell Voltage**
    - Alerts if imbalance exceeds threshold
4. **Safety & Protection:**
    - ESP32 can control load or charging based on **over/under-voltage**
    - Optional: add BMS or passive balancing for protection

7. Advantages of This Design

Feature	Advantage
Single Pack+ / Pack-	Compatible with standard 3S packs
High accuracy	INA226 + ADS1115 16-bit ADC
Bidirectional current	Measures both charging and discharging
Minimal hardware	Only INA226 + ADS1115 + ESP32
Detect cell imbalance	Measures individual cell voltages
Scalable	Can extend to 4S/5S by adding more ADS1115 channels

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8. Optional Enhancements

- **Cell balancing:** Passive resistors + MOSFETs controlled by ESP32
- **Data logging / monitoring:** ESP32 can send readings over Wi-Fi / Bluetooth
- **Overcurrent protection:** Add current limits in firmware based on INA226 readings

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9. Summary

- **System Components:** ESP32, INA226, ADS1115
- **Measurements:** Pack voltage, pack current, individual cell voltages
- **Limitations:** Cannot measure individual cell current in series (not needed)
- **Wiring:** High-side INA226 shunt for current, ADS1115 differential for cell voltages
- **Safety:** Monitors cell voltage, can implement software protection

Conclusion:
This design efficiently monitors a **3S Li-ion pack** using minimal hardware, with **accurate pack current, pack voltage, and individual cell voltage measurements**, all while maintaining a **single Pack+ / Pack- terminal setup**.