# 2025 TEEP Progress Report Week-18

## 1. Introduction

During the development of my online Battery Management System (BMS) project, I designed a setup using an **ESP32**, an **ADS1115 16-bit ADC**, three **Li-ion cells connected in series (3S configuration)**, and a standard **3S Li-ion charger**. My primary goal was to measure and publish the following information to the internet in real time:

- Individual cell voltages
- Estimated state of charge (SOC) for each cell
- Pack current during charging and discharging
- Overall health and performance of the battery pack

Throughout the week of working on this system, the most significant problem I encountered was an issue with current measurement when the charger was connected. The following report explains this issue in extensive detail.

---

# 2. System Overview

The system was built with the following components:

### 2.1 ESP32

Used as the main microcontroller and WiFi module for cloud connectivity.

### 2.2 ADS1115 ADC

Used to read:

- Scaled-down cell voltages (through resistor voltage dividers)
- Voltage across a current-sensing element (shunt resistor or sensor)

The ADS1115 was powered from the ESP32 and shared the same reference ground.

### 2.3 Battery Pack (3S)

Three 18650/21700 Li-ion cells in series:

- Cell 1: 3.0 V – 4.2 V
- Cell 2: 6.0 V – 8.4 V (relative to pack ground)
- Cell 3: 9.0 V – 12.6 V

The total pack voltage can reach up to ~12.6 V.

### 2.4 3S Charger

The charger used was an off-the-shelf 3-cell Li-ion charger which performs constant current (CC) and constant voltage (CV) charging.

---

# 3. The Core Problem

## 3.1 Problem Summary

When the battery pack was connected to the charger, the ADS1115 consistently measured **charger current** instead of **actual battery pack current**.
This happened both during charging and sometimes even during transitions where load and charging overlapped.

This behavior produced incorrect current values and made the system's battery monitoring functions unreliable.

---

## 4.1 What the System Was Supposed to Measure

The intended measurement was the **true current flowing into or out of the battery pack**, meaning:

- During discharge: current from the battery to the load
- During charge: current from the charger into the battery pack

This is what a proper BMS should measure, because SOC estimation and health calculations depend heavily on accurate current data.

## 4.2 What Actually Happened

Instead of measuring pack current, the ADS1115 returned a value that matched:

- The **output current from the charger**, not
- The **current actually entering the batteries**

This discrepancy was especially large during the CC/CV switching region of charging, where the charger intentionally varies its output.

---

## 5.1 Current Sensor Placement

The current sensing device (shunt resistor or analog current sensor) was installed in a position where it primarily measured **the current coming from the charger**, because:

- It was placed along the **charger's negative line**,
- Instead of being placed at the **actual battery pack negative terminal**, where all charging and discharging currents flow.

As a result, when the charger was connected, all the current that the charger produced flowed through the sensor, but **not necessarily all current entering the battery pack** passed through it.

### Example scenario:

1. The charger outputs current into the system.
2. Part of that current flows to the battery.
3. Another part may flow to any load connected in parallel.
4. Internal battery balancing (cell-to-cell transfer) does not show up at the sensor.

Your sensor only captures the current from Step 1.

---

## 5.2 Mismatched Ground Reference

The ADS1115 and ESP32 share a common ground that was tied to:

- Charger ground
- Load ground

- Sensor ground

But **not directly to the battery's true negative terminal**.

This causes multiple issues:

### A. Ground Shift During Charging

When a charger is connected, its internal circuitry creates a slightly elevated or slightly lowered ground potential because it regulates current dynamically.

This means the ADS1115 sees:

- A changing "zero" reference level
- A different ground potential than the battery ground
- Voltage differences that are not coming from the battery

This results in unstable readings.

### B. Incorrect Voltage Drop Measurement

A current sensor measures the voltage across a shunt resistor (in millivolts).
If the ground level shifts, even tiny changes cause large errors at the ADC input.

Because the charger modifies its output during CC/CV stages, the ground reference fluctuates and the ADS1115 interprets this incorrectly as current change.

---

## 5.3 Cell Voltage Divider Interaction

The voltage dividers used to measure individual cell voltages introduced additional coupling because they all referenced the same shared ground.

During charging:

- The charger alters the ground's electrical potential
- The voltage dividers reference that altered ground
- The ADS1115 interprets part of the charger's behavior as voltage drift in the cells

This gives inaccurate current AND voltage readings simultaneously.

## 5.4 Internal Battery Behavior Not Reflected in Measurement

Actual battery pack current is not always equal to the charger output current.

### Examples:

- Internal resistance causes slight delays in current flow
- The charger may pulse current rapidly (PWM-like behavior)
- A load may be connected in parallel with the charger
- Cells may self-balance internally

The current entering the cells is often different from the charger's displayed current.

But because your sensor was placed on the charger line:

- The ADS1115 always displayed charger current
- It did not show battery pack current
- It ignored internal battery or load-related current differences

---

# 6. Effects and Impact on the System

Because of this mismeasurement issue, the system experienced the following problems:

### 6.1 Incorrect Pack Current Values

The system could not distinguish between:

- Current going to the battery
- Current going to the load
- Balancing or redistribution currents

All measurements were biased toward charger output.

---

### 6.2 Unreliable SOC Calculation

State of Charge (SOC) algorithms rely on **coulomb counting** or **current integration**.
Since the current was not measured correctly:

- SOC became inaccurate
- The readings fluctuated
- The system could report wrong charge percentage values

---

### 6.3 Incorrect Cell Voltage Readings

Ground shifts from the charger influenced the ADS1115 voltage divider references, causing:

- Noise
- Incorrect cell voltage deltas
- Readings that appeared unstable or inconsistent

---

### 6.4 Unusable Real-Time Monitoring

Because the pack current and cell voltages were inaccurate, online reporting via ESP32 produced unreliable data.

This made the monitoring system unsuitable for any real-world application until the measurement issue is corrected.

---

# 7. Conclusion

Throughout the week working on this project, the main issue I faced was a **fundamental measurement error** caused by the placement of the current sensor and grounding configuration.

### Key summary of the problem:

- The ADS1115 was reading **charger current**, not **battery pack current**
- This happened because the current sensor was physically located on the charger's current path rather than the pack current path
- Ground reference shifts caused by the charger resulted in inaccurate ADC readings
- Cell voltage dividers also relied on the shifted ground, worsening the issue
- All SOC, voltage, and current data became unreliable whenever the charger was connected

## Learning Reflection :

Working on this project brought a mix of motivation and frustration, creating several learning conflicts along the way. At first, I felt confident about the design and expected the measurements to work smoothly. But when the system started showing incorrect current readings during charging, confusion set in. I struggled between trusting my wiring and doubting my understanding of how current actually flows in a 3S system. Each failed test added pressure, making me question whether the issue was in the hardware, the ADS1115, or my approach altogether. There were moments of stress and even discouragement when the results didn't match my expectations. But at the same time, each failure pushed me to analyze the problem deeper. This conflict between frustration and curiosity became a key part of the learning process, ultimately helping me understand the system more clearly.

Thank you