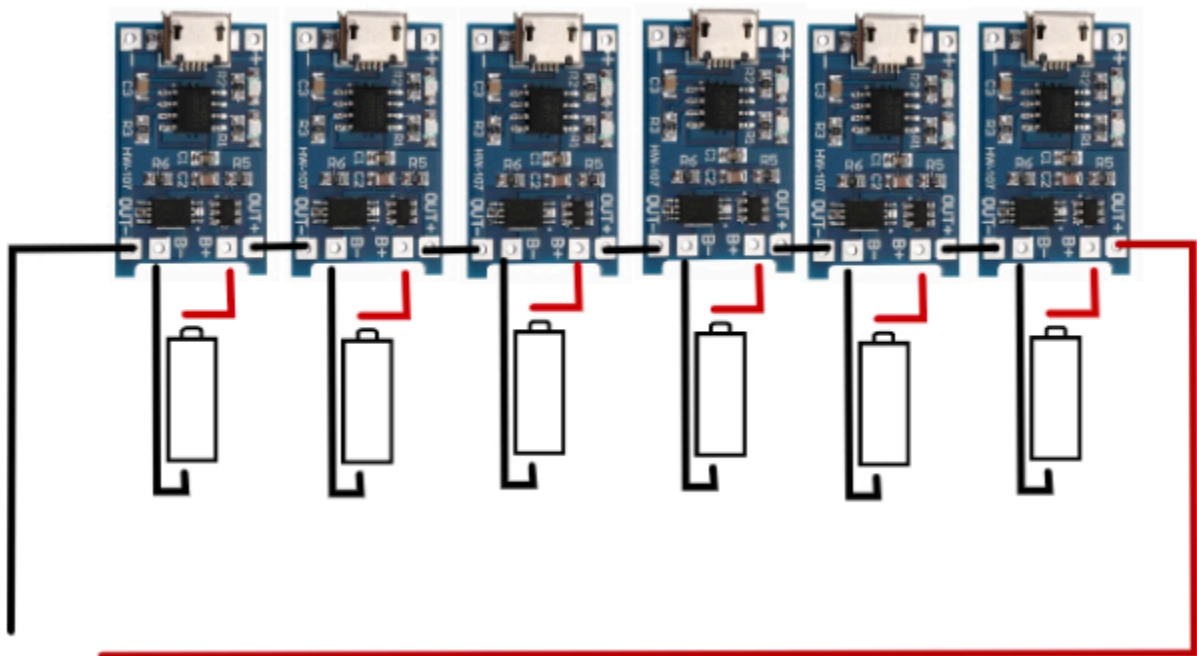


# Design and Analysis of Series Connection of TP4056-Based Lithium-Ion Charging Modules Using OUT+ and OUT-

## I. Introduction

The increasing demand for compact and energy-efficient electronic systems has led to the widespread use of lithium-ion (Li-ion) batteries. Many embedded platforms, such as microcontroller-based systems and Internet of Things (IoT) devices, commonly rely on single-cell Li-ion batteries due to their simplicity and availability. However, certain applications—such as motor drivers, industrial sensors, and higher-power embedded systems—require supply voltages exceeding the nominal 3.7 V provided by a single Li-ion cell.

To meet higher voltage requirements, multiple Li-ion cells are often connected in series. This introduces significant challenges in charging, protection, and voltage balancing. The TP4056 is a linear charging IC designed exclusively for charging a single Li-ion cell. Despite this limitation, TP4056 modules are sometimes incorrectly used in series configurations to form multi-cell battery packs. This paper analyzes such configurations and clarifies the correct and incorrect use of TP4056 modules when series connection is required.



## II. Overview of the TP4056 Charging Module

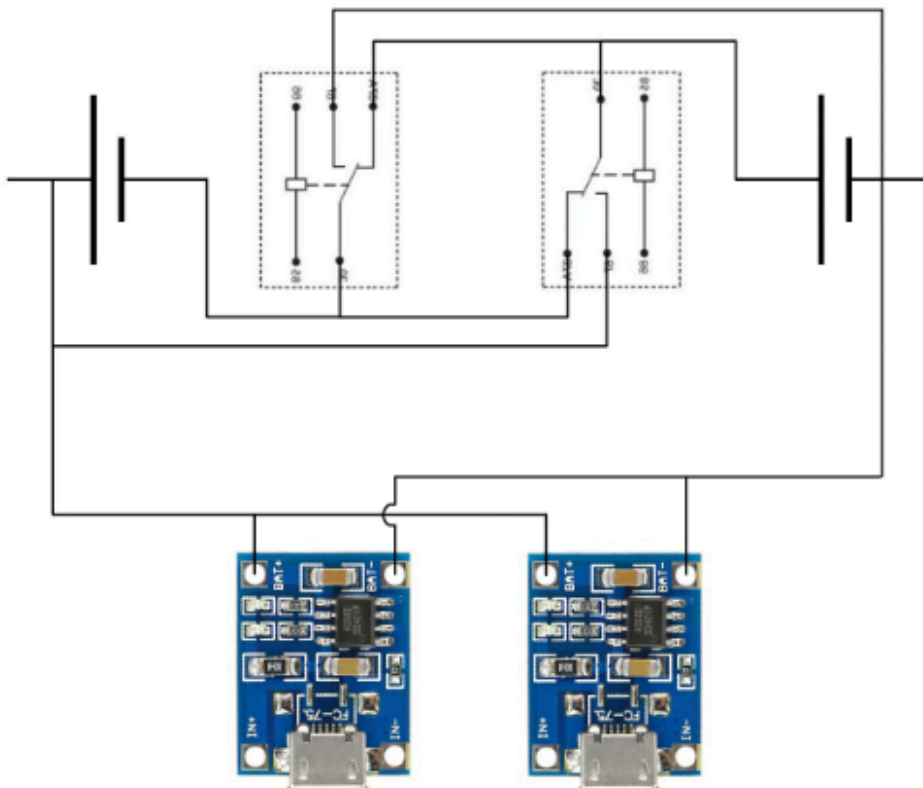
### A. TP4056 Charging Principle

The TP4056 is a constant-current/constant-voltage (CC–CV) linear charger designed for a single 3.7 V Li-ion or Li-polymer battery. It operates from a 5 V input supply and regulates the charging voltage to  $4.2 \text{ V} \pm 1\%$ .

The charging process consists of:

1. **Pre-charge mode** for deeply discharged cells
2. **Constant current mode** for fast charging
3. **Constant voltage mode** for charge termination

The charging current is programmable using an external resistor.



## B. TP4056 Module Terminals

A standard TP4056 module includes the following terminals:

- **IN+ / IN-**: 5 V charging input
- **B+ / B-**: Direct battery connection
- **OUT+ / OUT-**: Protected output terminals

Most modules integrate a protection IC (typically DW01A) and dual MOSFETs (FS8205A), providing:

- Over-charge protection
- Over-discharge protection
- Over-current and short-circuit protection

The OUT+ and OUT- pins are electrically isolated from the battery during fault conditions, making them suitable for connecting external loads.

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## III. Series Connection Using OUT+ and OUT-

### A. Series Connection Concept

In a series configuration, the positive terminal of one cell is connected to the negative terminal of the next cell, resulting in additive voltages. For example, two 3.7 V Li-ion cells connected in series produce a nominal voltage of approximately 7.4 V.

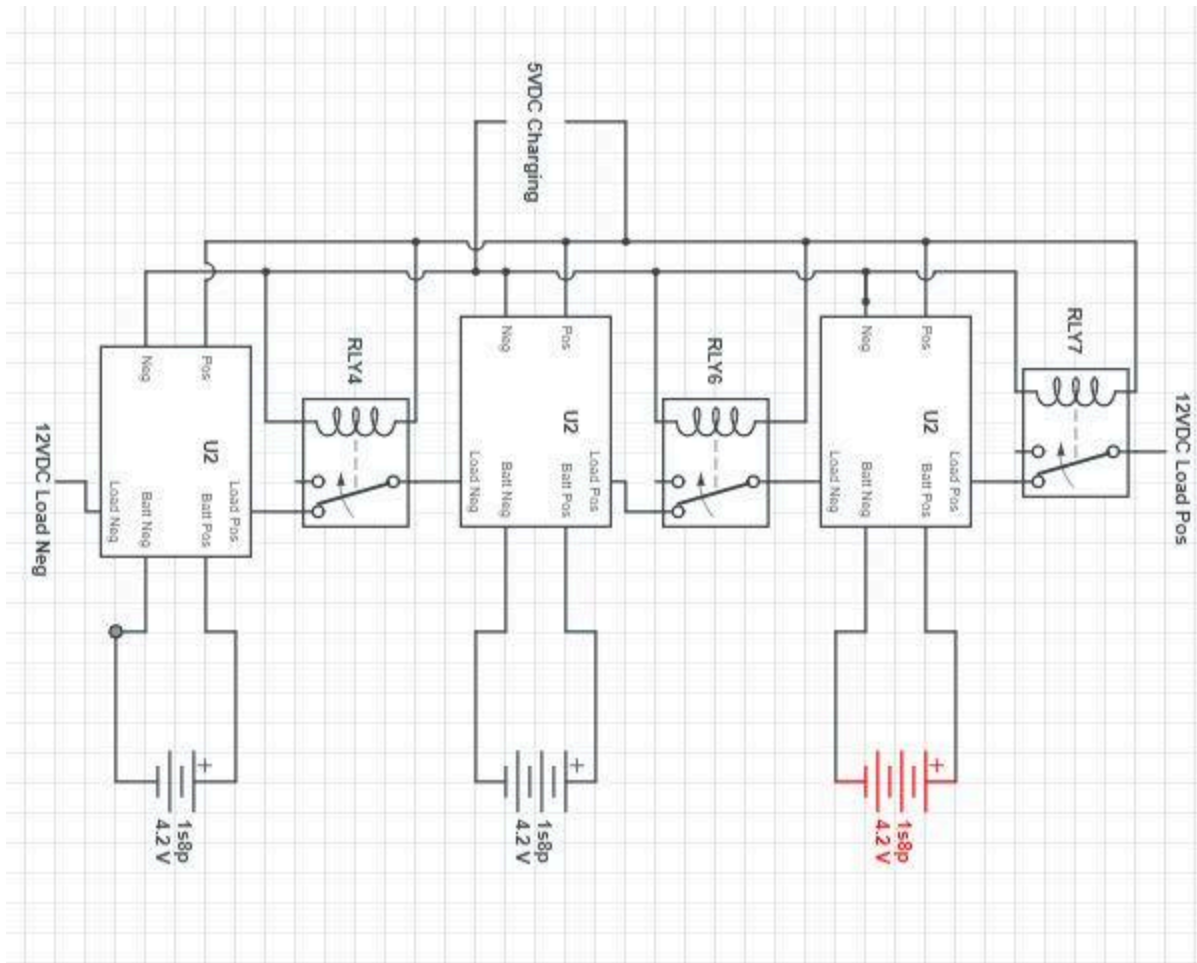
When using TP4056 modules, the series connection is typically attempted using the **OUT+ and OUT- terminals**, rather than the battery terminals (B+ and B-), in order to preserve protection functionality.

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### B. Example: Two-Cell Series Configuration

In a two-cell series configuration:

- OUT- of TP4056 Module 1 is connected to system ground
- OUT+ of Module 1 is connected to OUT- of Module 2
- OUT+ of Module 2 becomes the system positive terminal



## IV. Limitations of Charging Series-Connected TP4056 Modules

Although series connection via OUT+ and OUT- may appear electrically functional, the TP4056 is **not designed to charge series-connected cells**. Several critical limitations make such configurations unsafe and unreliable.

### A. Lack of Cell Balancing

In series-connected battery packs, cell balancing is essential to ensure that all cells maintain equal voltage levels during charging and discharging. The TP4056 operates independently on each cell and has no mechanism to compare or balance voltages between cells. Over time, voltage mismatch can result in:

- Overcharging of one cell

- Undercharging of another cell
  - Reduced battery lifespan
  - Increased risk of thermal runaway
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## B. Common Ground Reference Issue

The TP4056 uses a common ground reference for both input and battery terminals. When multiple TP4056 modules are connected in series, this reference is violated, leading to incorrect voltage sensing and unstable charging behavior.

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## C. Protection Circuit Constraints

The onboard protection circuit monitors only individual cell parameters. It does not provide:

- Pack-level voltage protection
- Inter-cell fault detection
- Series over-voltage monitoring

As a result, the protection system is insufficient for multi-cell battery packs.

## V. Acceptable Use Case: Series Connection for Discharge Only

Despite its limitations, series connection using OUT+ and OUT– can be acceptable **only for discharge**, provided that strict conditions are met.

### A. Safe Operating Conditions

- Each Li-ion cell is charged **individually** using its own TP4056 module
  - Each TP4056 charger uses an **isolated 5 V supply**
  - Series connections are applied **only after charging is complete**
  - No charging current flows through the series-connected outputs
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## B. Application Scenarios

This approach may be used in laboratory prototypes or educational projects where:

- Cost constraints are critical

- Charging and discharging phases are strictly separated
- Continuous monitoring is implemented

However, it is not recommended for commercial or long-term deployments.

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## VI. Comparison with Dedicated Multi-Cell Charging Solutions

Feature	TP4056	Multi-Cell Charger / BMS
Supported Cells	1S	2S, 3S, or higher
Cell Balancing	No	Yes
Pack Voltage Control	No	Yes
Charging Safety	Limited	High
Industrial Suitability	No	Yes

Integrated solutions such as **BQ241xx**, **BQ257xx**, or dedicated Battery Management Systems (BMS) are specifically designed to manage series-connected cells safely and efficiently.

## VII. Conclusion

This paper has presented a detailed analysis of using TP4056 charging modules in series via the OUT+ and OUT– terminals. While such configurations may provide higher output voltage during discharge, the TP4056 is fundamentally unsuitable for charging series-connected lithium-ion battery packs. The absence of cell balancing, pack-level protection, and electrical isolation introduces significant safety risks. For applications requiring series-connected batteries, dedicated multi-cell charging and battery management solutions must be employed. The TP4056 should remain limited to single-cell charging applications to ensure safe and reliable operation.

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## References

- TP4056 Datasheet, NanJing Top Power ASIC Corp.
- DW01A Lithium-Ion Battery Protection IC Datasheet
- Linden, D., & Reddy, T. B., *Handbook of Batteries*, McGraw-Hill