

Designing A Li-Ion Battery Charger and Load Sharing System With Microchip's Stand-Alone Li-Ion Battery Charge Management Controller

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INTRODUCTION

Batteries often serve as the main energy source for portable electronic devices. Although they depend on batteries, portable consumer electronic products, such as GPS devices and multi-media players, often consume energy directly from an ac-dc wall adapter or accessory power adapter (or "Auto Adapter") when the battery is low or the device is in a stationary mode.

Due to their cost effectiveness over their useful life, rechargeable batteries are often used for the power source of the portable electronic device. Attributes such as "relatively high energy density" and "maintenance free" make Lithium-Ion (Li-Ion) batteries popular in the portable consumer electronic products. Refer to the application note, AN1088, *"Selecting the Right Battery System For cost Sensitive Portable Applications While maintaining Excellent Quality"* (DS01088) for characteristics of Li-Ion batteries. Some examples of how to properly design with Li-Ion batteries will be discussed in this application note.

Depending on the product design or local government regulations, rechargeable batteries are often charged from inside the handheld devices or from battery charging cradles. Due to the safety concerns or design concepts in certain regions, some batteries are required to be removed from the portable device prior charging activities are initiated.

However, most of the time, batteries are designed to be recharged while the devices are still in the operational mode. An end user can extend the run time while refilling the energy back to the battery for the next mobile action. The power source now has to supply the device while charging the battery. The battery can deliver energy to the system load when the power source is absent as depicted in Figure 1.

Portable electronic devices have dramatically changed the way people live and work. They play an important role in a person's daily life from every day tasks to entertainment. With the emerging technologies that are available today, portable electronic designers are trying to integrate more features into smaller and lighter form factors while extending the system run times.

This application note shows how to take advantage of Microchip's fully integrated simple Li-Ion battery charge management controllers with common directional control to build a system and battery load sharing circuitry. The solutions are ideal for use in cost-sensitive applications that can also accelerate the product time-to-market rate.

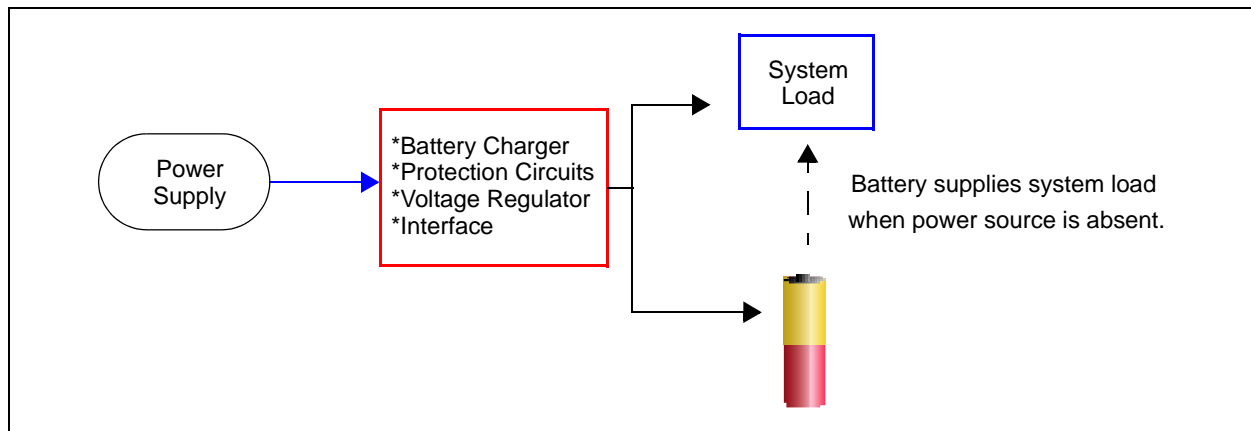


FIGURE 1: Typical Portable Power Source.

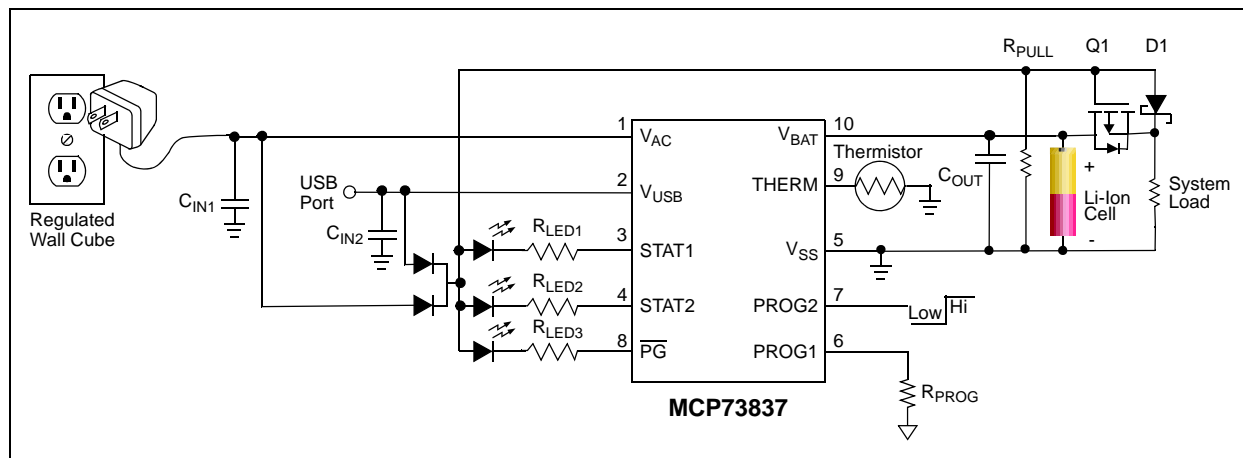


FIGURE 2: Typical System and Battery Load Sharing Application.

DESCRIPTION

This application note shows how to design a simple load sharing system using Microchip's popular MCP73837 device for cost-sensitive applications. Refer to the MCP73837/8 Data Sheet, "Advanced Stand-Alone Li-Ion / Li-Polymer Battery Charge Management Controller with Autonomous AC-Adapter or USB-Port Source Selection", (DS22071).

References to documents that treat these subjects in more depth and breadth have been included in the "Reference" section.

BATTERY CHARGER AND SYSTEM LOAD DESIGN SPECIFICATIONS AND APPLICATION DESCRIPTION

The example system load consumes a maximum current of 500 mA when all applications are running at the same time. A 950 mAh rated Li-Ion battery is available to operate the example portable system for nearly two hours during intensive load operations. The actual battery run time may vary based on the system load, battery age, and environmental conditions.

The input power should supply the system load and charge the battery when a battery is present in the system. When the input power source is removed, the system is supported by the battery. When the system load and the battery draw more energy than the supply can offer, the system load takes priority over the battery charger.

Design Specifications

- **System Load Input Voltage Range:**
 - 4.5V - 6.5V from ac-dc adapter (1A)
 - 5V from USB port (100 mA/500 mA)
 - 3V - 4.2V from 1-cell Li-Ion battery (950 mAh)
- Constant Charge Current:
 - 0.5C (The battery manufacturer recommended value)
 - 100 mA / 500 mA (Charge from USB port)
- Precondition Current:
 - 0.1C or recommended value
- Termination Current:
 - 0.07C
- Charge Status and Power Good Indicators
- Safety Timer: Turn charger off after 6 hours of continuous charging

Theoretical Capacity - “C” Rate

Definition: The theoretical capacity of a battery is determined by the amount of active materials in the battery. It is expressed as the total quantity of electricity involved in the electrochemical reaction and is defined in terms of coulombs or ampere-hours. The “ampere-hour capacity” of a battery is directly associated with the quantity of electricity obtained from the active materials.

EXAMPLE 1: “C” RATE

- Theoretical Capacity (Coulombic)
 - Amount of Active Material
ampere-hour (Ah)

$$I = M \times C_n$$

Where:

- I = discharge current, A
- C = numerical value of rated capacity, Ah
- n = time, in hours, at which C is declared
- M = multiple or fraction of C

Example:

- 1.7Ah Li-Ion Battery
- 1C Rate = 1.7A
- 0.1C or C/10 Rate = 170 mA

LITHIUM-ION (LI-ION) / LITHIUM-POLYMER (LI-POLYMER) BATTERIES

Here are some important attributes when selecting a battery for an application:

1. Internal Resistance,
2. Operational Load Current,
3. Energy Density (Size & Weight),
4. Charge/Discharge Cycles (Life Cycle),
5. Capacity (dominates the operational duration without external power source present).

Like most engineering work, these key attributes do not exist in the same technology. There is always a trade-off between them when selecting the battery chemistry for a portable application. Refer to Microchip's AN1088 *“Selecting the Right Battery System for Cost-Sensitive Portable Applications While Maintaining Excellent Quality”* for the details of battery chemistry comparisons.

Li-Ion batteries have played an important role in today's portable world because of the advantages in high energy density, low maintenance requirement, relatively low self discharge rate and higher cell voltages. 1-cell Li-Ion batteries especially enjoy the largest share of the Li-Ion battery market while 1-cell and 2-cell applications are available in more than 70% of the total available market.

Li-Polymer batteries which are also recognized as Li-Ion Polymer batteries are similar in terms of chemistry with Li-Ion batteries. Li-Polymer can be charged using the same algorithm as Li-Ion batteries because of their similar characteristics. The flexible form factors and very low profile to fit inside the compact applications make Li-Polymer an ideal candidate for MP3 Players and Mobile Phones.

Note: The major drawbacks of Li-Ion batteries are higher initial cost and the aging effect. Li-Ion batteries age over time regardless of the number of cycles that have been reached. A protection circuit is required for Li-Ion batteries to prevent overvoltage during charge cycle and undervoltage during the discharge cycle; overcurrent as well in both directions.

Batteries usually occupy a considerable amount of space and weight in today's portable devices. The energy density for each chemistry dominates the size and weight for the battery pack. Li-Ion has advantages in both energy density weight and energy density volume among other available battery technologies.

SELECTING THE BATTERY CHARGE MANAGEMENT CONTROL CIRCUIT

The emerging semiconductor technologies shorten the design cycles and simplify design methods for the consumer product designers by integrating circuits into a single chip. The first step is to decide to design a custom charge control management circuit or adapt a stand-alone charge IC.

Stand-Alone Charge Management Controller

Microchip's MCP73837 device is selected to complete the design because it dramatically reduces the software/hardware design time and simplifies the PCB layout. The MCP73837 device that is used in this example has 4.2V battery voltage regulation, 10% pre-conditioning ratio and 7.5% EOC (end of charge) ratio. The general features of the MCP73837 device are listed below:

- High Accuracy Preset Voltage Regulation: $\pm 0.5\%$
- Available Voltage Regulation Options:
 - 4.20V, 4.35V, 4.4V or 4.5V
- Complete Linear Charge Management Controller:
 - Autonomous Power Source Selection
 - Integrated Pass Transistors
 - Integrated Current Sense
 - Integrated Reverse Discharge Protection
- Constant Current / Constant Voltage Operation with Thermal Regulation
- Selectable USB-Port Charge Current:
 - 100 mA maximum (Logic Low) / 500 mA maximum (Logic High)
- Programmable AC-Adapter Charge Current:
 - 15 mA - 1000 mA
- Two Charge Status Outputs
- Power-Good Monitor:
 - MCP73837 Device
- Timer Enable:
 - MCP73838 Device
- Automatic Recharge
- Automatic End-of-Charge Control:
 - Selectable Charge Termination Current Ratio
 - Selectable Safety Timer Period
- Preconditioning of Deeply Depleted Cells
- Battery Cell Temperature Monitor
- UVLO (Undervoltage Lockout)
- Automatic Power-Down when Input Power is Removed
- Low-Dropout (LDO) Linear Regulator Mode
- Minimum External Components Required

- Numerous Selectable Options Available for a Variety of applications:
 - Refer to the MCP73837/8 Data Sheet, Section 1.0 "Electrical Characteristics for Selectable Options"
 - Refer to the MCP73837/8 Data Sheet, "Product Identification System" for Standard Options
- Temperature Range: -40°C to +85°C
- Packaging:
 - 10-Lead 3 mm x 3 mm DFN
 - 10-Lead MSOP

Note: Refer to the MCP73837/8 Data Sheet (DS22071) for detailed descriptions.

Common Cathode Diode

Figure 3 shows a common cathode diode to drive LEDs and supply power to the system load when either source from an ac-dc adapter or a USB port is used. This prevents reverse current from feeding into the other source.

The common cathode diode can be left out of the design if automatic switching between the ac-dc adapter and the USB port feature is not required or a different charge IC, which does not have autonomous dual power source selection, is used in the design.

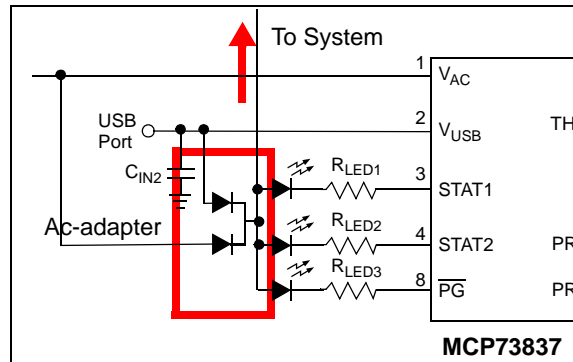


FIGURE 3: Common Cathode Diode Connection Diagram.

CONNECTING THE SYSTEM LOAD TO THE BATTERY

Some designers may simply connect the system load to the battery cell. This allows the system to be powered by Li-Ion batteries without proper regulation. It is not encouraged to attach the system load directly to Li-Ion batteries when using a stand-alone Li-Ion battery charge management controller with automatic termination feature.

Here are several reasons that the system load is not recommended to be connected directly to the battery terminals:

1. The charge may never end. Most Li-Ion battery chargers are based on Constant Current and Constant Voltage (CC-CV) modes. The termination is based on the ratio of charge current and preset constant current (Fast Charge). If the system draws current from the battery, the charge current will never meet the termination value. This causes the non-termination of the charge management circuit.

Note: The MCP73811/2 Li-Ion battery charge management controllers with no auto-termination may be a viable solution for the type of applications that are designed to simply connect the system load to the Li-Ion battery.

2. The total system current is limited by the charge current because the charger will deliver total system and battery charging current through the output pin. This solution may be feasible for some applications that run on constant current, but it is not recommended.

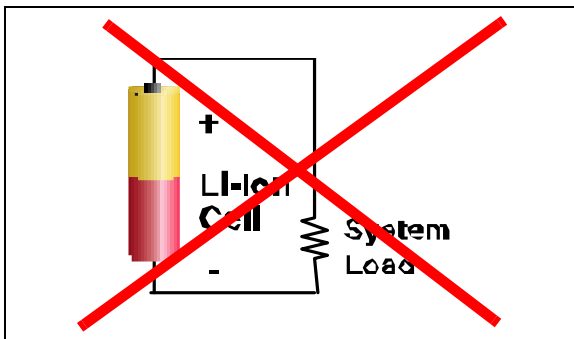


FIGURE 4: Do Not Connect the System Load Directly to the Battery When Charging with the Li-Ion Battery Charge Management Controller with Automatic Termination Feature.

3. A switch can be introduced to the system to turn it off before charging the batteries. This method limits the way that portable electronics operates and is only suitable for finite applications.

Selecting The Pull-Down Resistor

Figure 5 represents the pull-down resistor (R_{PULL}) to make sure that the P-Ch MOSFET (Q1) turns on when the input sources are removed. When the input sources are absent, the R_{PULL} pulls the gate to zero allowing current to flow out of the battery.

R_{PULL} value can be any reasonable value resistor. However, the R_{PULL} value should not be too small. A small R_{PULL} value wastes unnecessary current when the input sources are present. A 100 k Ω R_{PULL} resistor is recommended in this design which consumes about 50 μ A when $V_{IN} = 5$ V.

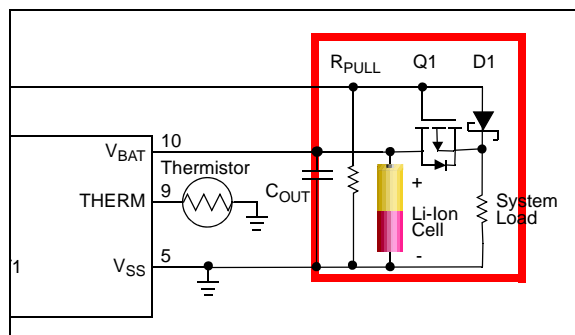


FIGURE 5: Current Directional Control Circuit.

Selecting The MOSFET

The nature of the MOSFET makes it the best candidate for current direction control. A P-Channel MOSFET is selected to complete this circuit as Figure 6 depicts, when V_{IN} is available, the gate of Q1 is high. With Q1 off, current does not flow from the Li-Ion battery to the system load. The system load requirements are provided by the input source when the Li-Ion battery is charged at the same time. When the gate of Q1 is low, Q1 turns on and allows the Li-Ion battery to supply the system as shown in Figure 7. The MCP73837 device V_{BAT} pin is also disabled when V_{IN} is absent.

Note: It is important to select a proper gate threshold voltage range so the MOSFET will be turned on.

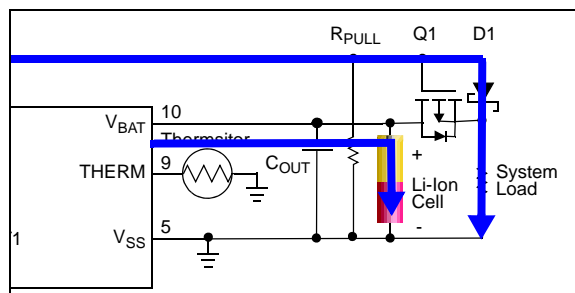


FIGURE 6: Q1 is Off When Gate is High and No Current Flows from the Battery Cell to the System Load.

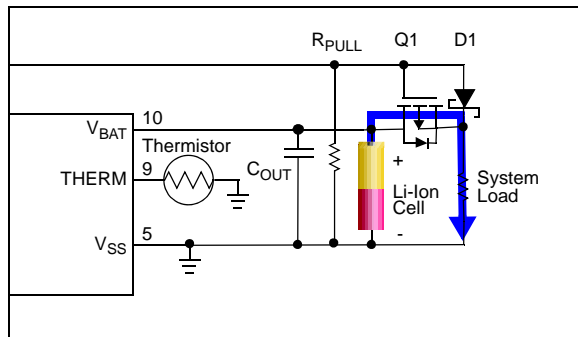


FIGURE 7: Q1 is On When the Gate is Low and Current Flows from the Battery Cell to the System Load.

Selecting The Diode

A diode, D1 in Figure 7 is required to prevent reverse current from flowing to the power source. Selecting the right diode can minimize the leakage current and the forward voltage drop from the power source to the system load. A schottky diode, which has lower forward voltage drop, is recommended.

Note: The Average Forward Current has to be rated greater than the maximum system load current for the application.

Co-packaged MOSFET + Schottky Diode

Semiconductor manufacturers provide a MOSFET and Schottky diode in one small package to save board space and cost. A typical SO-8 packaged low forward voltage drop Schottky diode and power P-Ch MOSFET is used for demonstration in this application note.

CHARGE PROFILE WITH SYSTEM LOAD

Figure 2 shows a complete system load and battery power path management circuit, which was designed for demonstration purposes in this application note. The system load was set up at a constant 500 mA rate. A deeply depleted 950 mAh Li-Ion battery was used and charged by Microchip's MCP73837 device. A fast charge current of USB_{High} was selected to charge 450 mA in the Constant Current Mode. The MCP73837 was designed to charge at a typical 450 mA constant current when USB_{High} is selected and assured not to exceed the 500 mA limit when a high-power USB port is available.

Note: The USB Specification clearly defines that a device may either be low-power at 100 mA loads or high-power, consuming up to 500 mA loads. All devices default to low-power. The transition to high-power is under software control. It is the responsibility of the software to ensure that adequate power is available before allowing devices to consume high-power. The number of "unit loads" a device can draw is an absolute maximum, not an average over time. (Designers should obtain the latest design specification and detailed information from the USB-IF, if USB peripherals are going to be implemented in a project.)

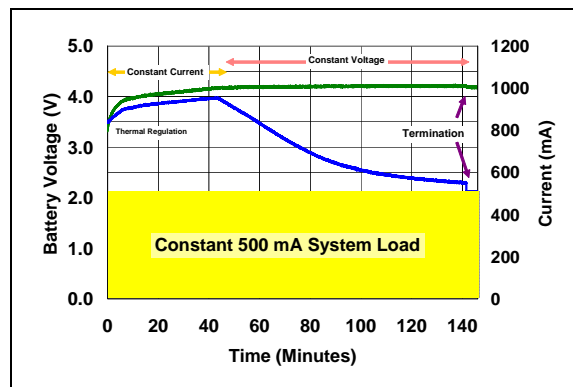


FIGURE 8: 450 mA Constant Charge Current Li-Ion Battery Charge Profile with a Constant 500 mA System Load.

Stage 1: Preconditioning - Preconditioning is employed to restore a charge to deeply depleted cells. When the cell voltage is below the designed threshold voltage, the cell is charged with a constant current of 0.1C maximum. This period is hard to see from Figure 8 because the V_{BAT} rises above 3V in a very short period of time and enters the Constant Current (Fast Charge) mode.

Stage 2: Constant Current - Once the cell voltage has risen above the preconditioning threshold, the charge current is increased to perform fast charging. The fast charge current should not be more than 1C. A fast charge current of 450 mA (~ 0.5C) is used in this example. The thermal foldback period demonstrates temperature regulation by limiting the current during the Fast Charge Period which also improve the reliability and prolongs the life of the charger IC.

Stage 3: Constant Voltage - Fast Charge ends and the Constant Voltage mode is initiated when the cell voltage reaches 4.2V (4.35V, 4.40V and 4.5V options are also available for the MCP73837/8 for various applications). In order to maximize the capacity, the voltage regulation tolerance should be better than $\pm 1\%$. The MCP73837 device provides a $\pm 0.5\%$ superior voltage regulation tolerance to deliver maximum battery run time after each completed charging cycle.

Stage 4: Termination - Charging is typically terminated by one of two methods: charge current termination threshold or a timer (or a combination of the two). The MCP73837 device employs the end of charge (EOC) methods of charge current termination threshold, safety timer and shutdown. Figure 8 shows that the minimum current is reached before time-out occurs. The MCP73837 device monitors the charge current during the constant voltage stage and terminates the charge when the charge current diminishes below approximately 0.07C (5%, 7.5%, 10%, and 20% options are available for the MCP73837/8 for various applications).

Note: It is not recommended to continue to trickle charge Lithium-Ion batteries.

Charging in this manner replenishes a deeply depleted battery in about 140 minutes at 0.5C. Advanced battery chargers employ additional safety features. For example, charging is suspended if the cell temperature is outside a specified window, typically 0°C to 45°C.

After 140 minutes, Figure 8 demonstrates that the power supply still supports a solid 500 mA system load when charge termination occurs and the battery charger went into a standby mode. During this standby mode, the MCP73837 device continues to monitor the V_{BAT} and will recharge the Li-Ion battery, once the regulated V_{BAT} voltage drops below 150 mV.

DISCHARGE THE LI-ION BATTERY

When a full charge cycle was completed, the input power source was removed. The P-Ch MOSFET was turned on to supply the system load with 0.53C and discharged the 950 mA Li-Ion battery as shown in Figure 9. The termination duration is load dependent and Figure 9 also shows the Li-Ion battery was not able to deliver 500 mA after 105 minutes. With approximately 0.5C discharge rate, the time should last about 2 hours. The main reason that the remaining 15 minutes are not available from this experiment is because the remaining capacity level is not enough to support 500 mA.

Note: When fully depleted, a Li-Ion battery may degrade its life cycle and should be avoided.

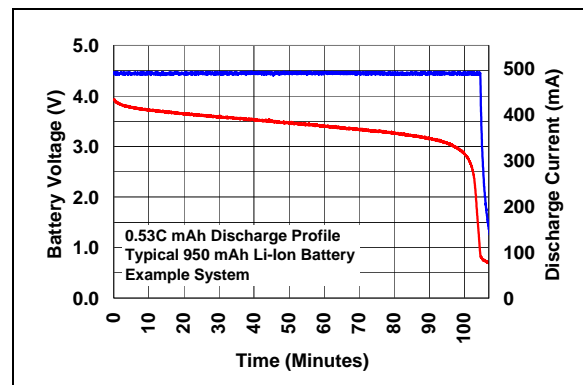


FIGURE 9: 500 mA Discharge Profile When V_{IN} is Removed.

CONCLUSION

System and battery load sharing power path management circuits are very common in portable applications. Adapting this simple design wisely can dramatically reduce the total system cost and product developing time in order to take advantages of using a fully integrated battery charge management controller.

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