

TI Designs: PMP9771 Reference Guide

Energy Storage Circuit for Uninterrupted Power Supply and Extending Alkaline Battery Lifetime



TI Designs

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Circuit Description

An alkaline battery and a boost converter are usually used to power the load system which requires high voltage, such as the motor driver in insulin pump. In this reference design, a lithium polymer battery is added to the output of the boost converter to absorb the pulse load current and extend the alkaline battery life time. The designed circuit also benefits uninterrupted power supply when the alkaline battery is out of charge.

Design Resources

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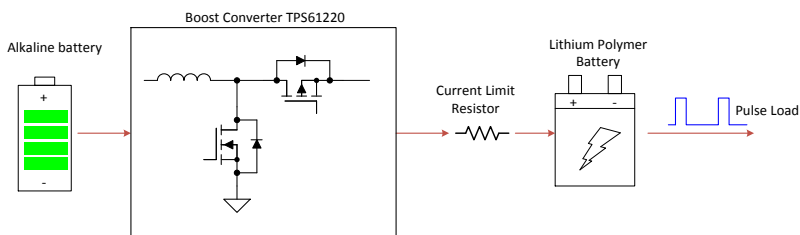
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1 Introduction

The primary alkaline battery is highly commercialized and sold in stores throughout the countries in standard package, because of its benefits: easy to be stocked longer, low cost, high energy density and being disposed easily. However, this battery has two disadvantages.

One disadvantage is the low output voltage. Alkaline batteries typically have a sloping discharge curve, starting from 1.6V at full charge and cutting off at 0.8V as shown in Figure 1. The voltage 0.8V~1.6V of one cell battery is not higher enough to power the DC motor / stepper motor in insulin pump or the RF module in thermostat when alkaline battery is selected in these applications. Thus, a low input voltage converter is needed to boost the low voltage to the required level.

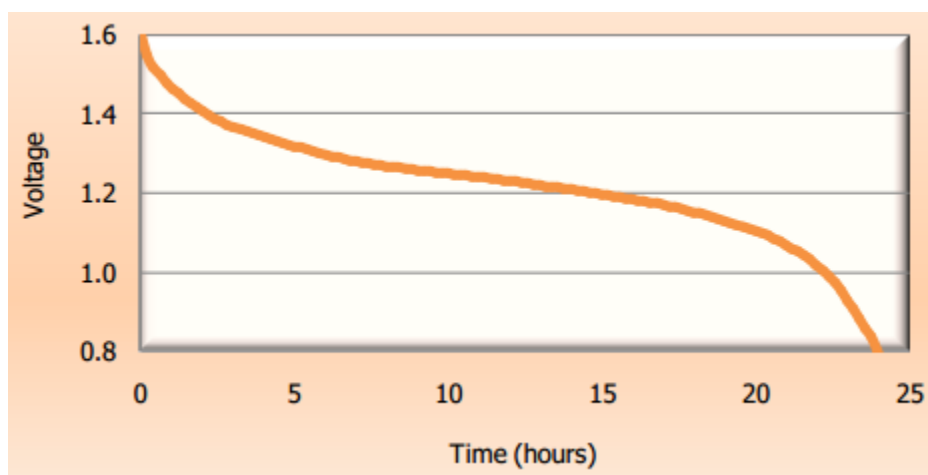


Figure 1 “Energizer” AA Alkaline Battery Discharge at 100mA

The other disadvantage is the limited output power. The typical effective resistance of a fresh alkaline battery will be approximately 150 to 300 milliohms, depending on size. The effective resistance will increase as the battery is discharged and reach to 500mohm or higher after 80% capacity discharged. This effective resistor limits the output power capability of the alkaline battery. Besides that, the output energy capability much depends on its discharge current, as show in Figure 2, the battery has greater capacity at small drain.

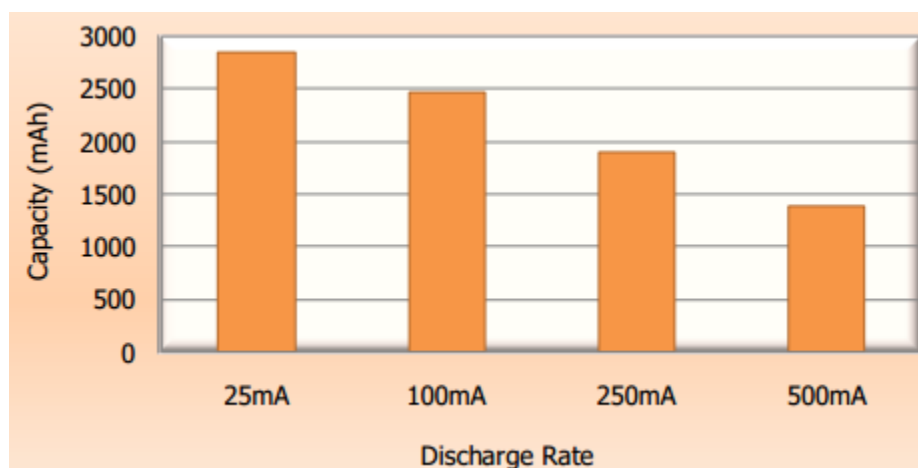


Figure 2: The Relationship of Capacity and Discharge Rate of “Energizer” AA Alkaline Battery

In the application which requires large pulse current but small average current, such as insulin pump, an energy storage component could help to smooth pulse current and increase the lifetime of the alkaline battery. Furthermore, the energy storage component can keep powering its load when the alkaline battery is out of charge and can't be replaced in time. This benefits the uninterrupted power supply for the important system load and fully utilizes the alkaline battery energy. In this reference design, a lithium polymer battery is selected as the energy storage component.

The following chapters will describe the design process and experiment data of the reference design.

2 Design Description

The block diagram of the design is shown in Figure 3. The TPS61220 boosts the alkaline battery output voltage to 4V to charge the lithium polymer battery through a resistor, which limits the output current of the TPS61220 and the alkaline battery. When the alkaline battery is out of charge and its voltage is lower than the TPS61220 UVLO voltage, typical value of 0.5V, the TPS61220 shuts down, and the load is only powered by the lithium polymer battery, until the bad battery is replaced to a new one.

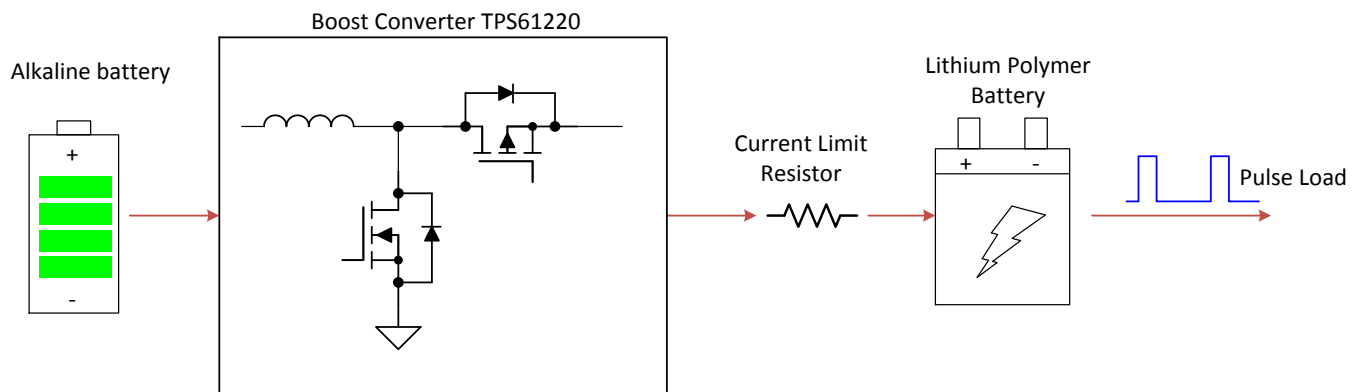


Figure 3: Block Diagram of the Design

2.1 Lithium Polymer Battery

Compared to the alkaline battery, the discharge current has much less impact on the capacity of the lithium polymer battery, as shown in Figure 4, discharge curve of a 720mAh lithium polymer battery from "Sony". The output capacity varies less than 5% in 0.2C (145mA), 0.5C (360mA) and 1C (720mA) discharge rate.

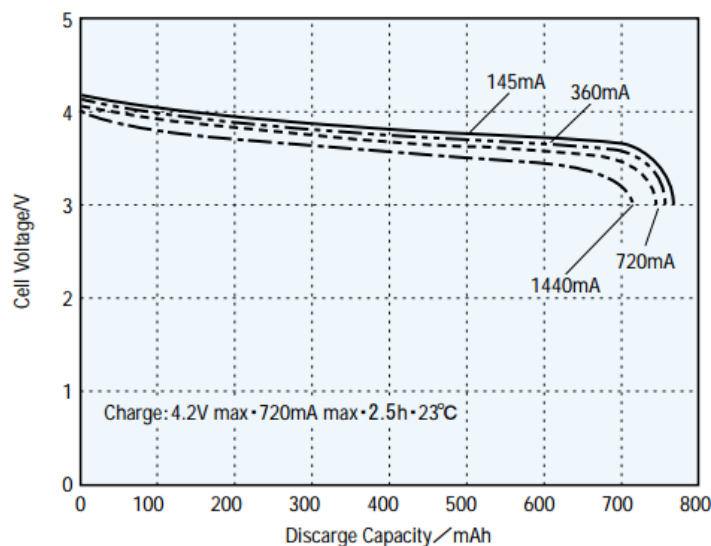


Figure 4: “Sony” 720mA Lithium Polymer Battery Discharge Curve

As in Figure 4, the operating voltage of the lithium polymer battery ranges from 3.3V to 4.2V. In this reference design, the maximum battery voltage is set to 4V because of the tradeoff of two factors: the battery's safety and its charge/discharge cycle in low operating voltage; on the other hand, the battery retains more energy after it is out of charge in high operating voltage. So the output voltage of the TPS61220 is set to 4V by its feedback divider resistor.

The current limit resistor is determined by the average load current and output voltage of the lithium polymer battery in normal operation condition. In order to have enough energy to power the load when the alkaline battery is removed, the voltage of the lithium polymer battery should be set to higher than 3.8V during normal operation as shown in Figure 5. The resistor value can be calculated by equation (1), where V_{OUT} is the TPS61220 output voltage, and V_{BAT_OUT} is the lithium polymer battery voltage, and I_{LOAD_AVE} is the average load current. In this reference design, a 40ohm resistor is selected to support 2.5mA average load current with 3.9V output voltage.

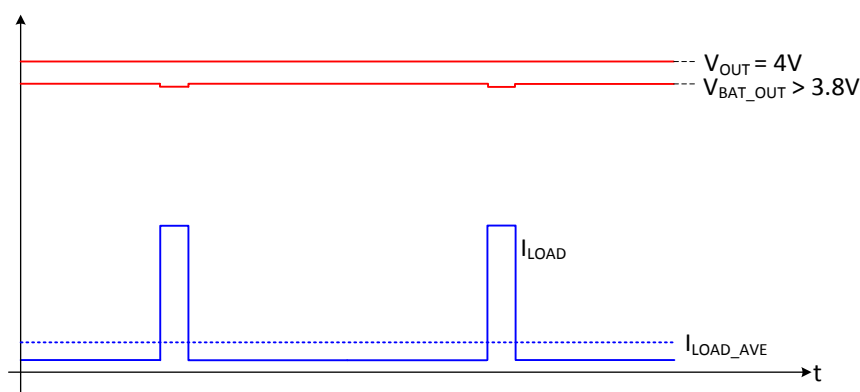


Figure 5: Schematic Diagram of Operating Waveform

$$R_{LIM} = \frac{(V_{OUT} - V_{BAT_OUT})}{I_{LOAD_AVE}} \quad (1)$$

The package of the resistor is determined by its maximum power loss that happens at minimum lithium polymer battery voltage condition, 3V at the worst case. So the maximum power loss of the current limit resistor is 25mW. The 0603 package is good enough to meet the power loss.

2.2 Boost Converter

A converter is needed to boost the low voltage of the alkaline battery to 4V to charge the lithium polymer battery with small charging current. The TPS61220 is a good candidate for this application because of its low input voltage and small quiescent current. The main electric characteristics of the TPS61220 are showed following:

- Input Voltage: 0.7V to 5.5V
- Input Under Voltage Lock Out: 0.5V (Typical)
- Input Peak Current Limit: 200mA minimum, 400mA typical
- Output: 1.8V to 6V
- Quiescent Current I_Q : 5.5 μ A typical, 8.4 μ A maximum.

The device is controlled by a hysteretic current mode controller. its inductor ripple current is kept constant in the range of 200 mA. Considering the worst case, maximum average input current of the device is defined by equation (2), where I_{SW_MIN} is the minimum peak current limit; i_{L_RIPPLE} is the current ripple of the inductor.

$$I_{AVE_MAX} = I_{SW_MIN} - \frac{I_{L_RIPPLE}}{2} = 200mA - \frac{200mA}{2} = 100mA \quad (2)$$

Then the maximum output current at the worst case can be calculated by equation (3)

$$I_{OUT_MAX} = \frac{V_{IN} \cdot I_{AVE_MAX} \cdot \eta}{V_{OUT}} \quad (3)$$

When $V_{IN} = 0.8V$, $V_{OUT} = 4V$, boost converter efficiency η is around 0.8, thus the minimum output current will be 16mA.

The quiescent current I_Q is the control circuit power dissipation of the boost converter. Normally, low quiescent current means high efficiency at light load. The Figure 6 shows the efficiency of this device at $V_{IN} = 0.8V, 1.2V, 1.5V$ and $V_{OUT} = 4V$ condition. The efficiency is higher than 70% at $I_{OUT} = 100\mu A$ and higher than 80% at $I_{OUT} = 10mA$.

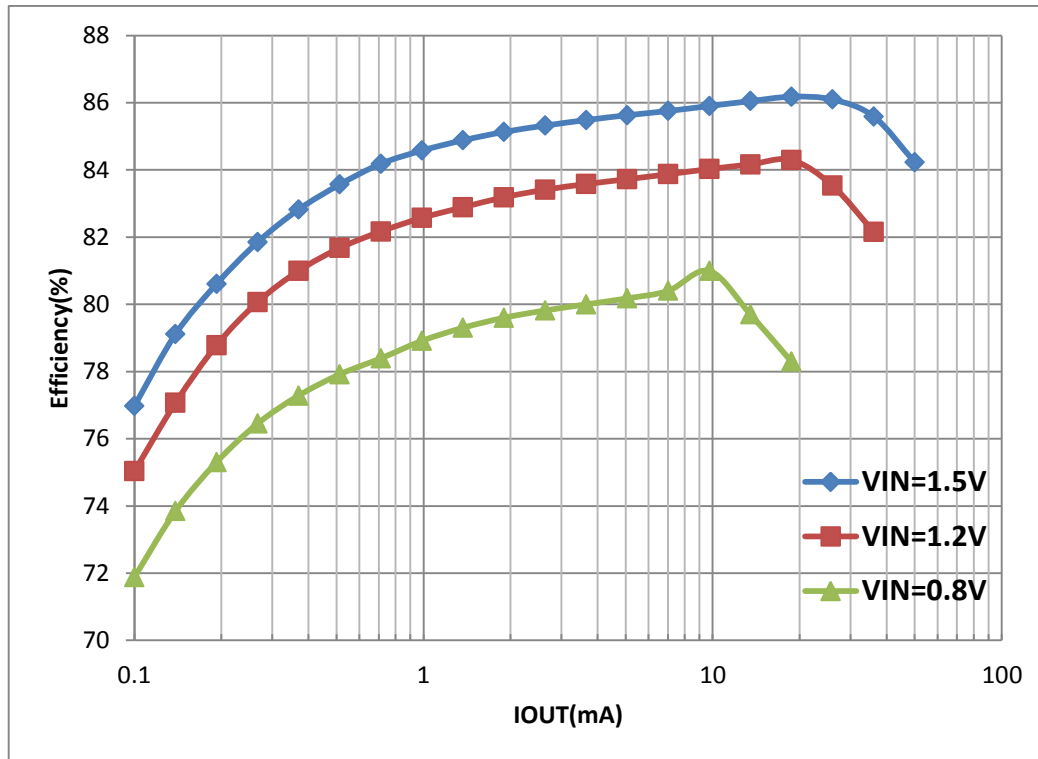


Figure 6: TPS61220 Efficiency at $V_{OUT}=4V$

2.3 Schematic

The schematic of the design is shown in Figure 7

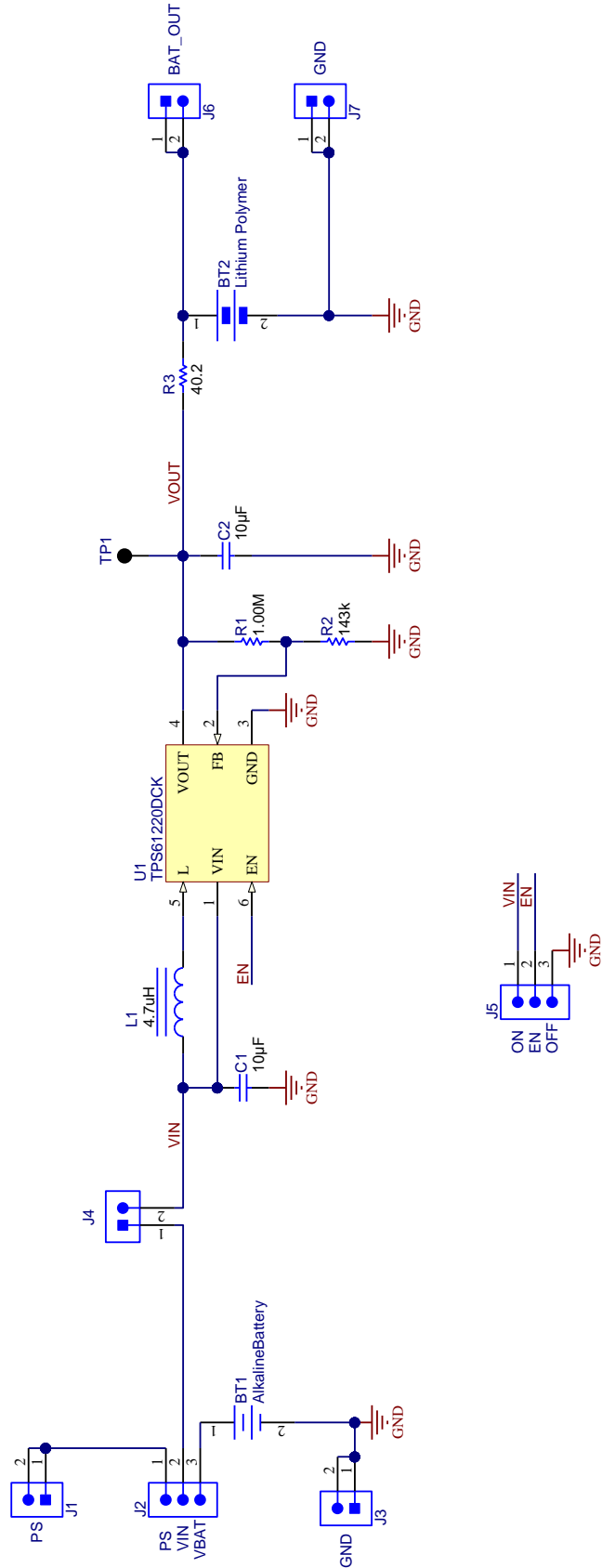


Figure 7: Schematic of the Reference Design

The function of the jumpers and connections in the schematic is shown in Table 1

Table 1 Jumper and Connection Description

J1	Power supply (PS) for the reference design; the voltage ranges from 0.7V to 3.2V.
J2	Jumper to select the input power for the TPS61220, PS or alkaline battery
J3,J7	GND
J4	Current meter can be inserted to detect the input current
J5	Enable or disable the TPS61220
J6	Output voltage of the lithium polymer battery
TP1	Output voltage of the TPS61220

3 Experiment Result

The measurement setup and test point of the operating waveform is shown in Figure 8

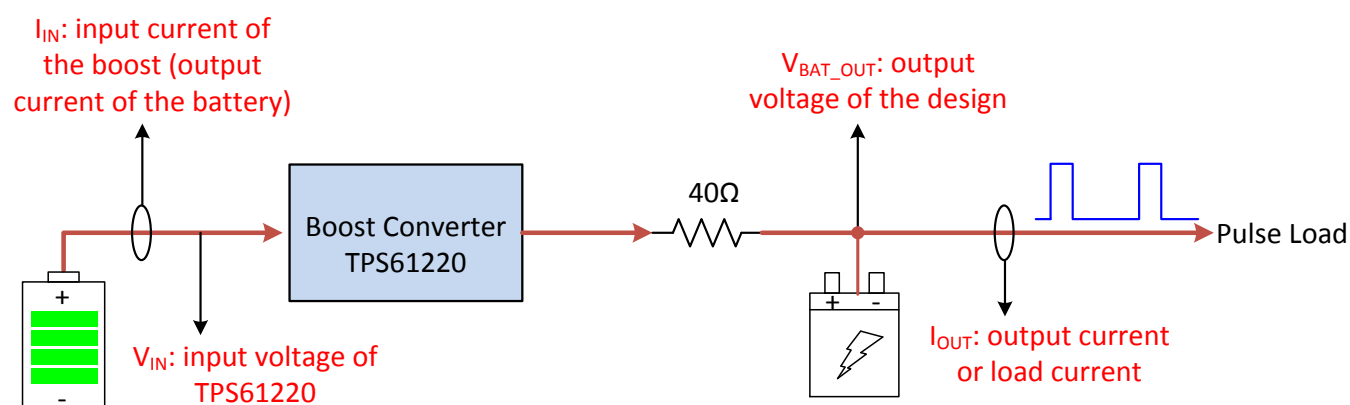


Figure 8: Setup for Measuring Operating Waveform

The load current is simulated by Figure 9. The period is 5 minutes with 150mA pulse current which last 5 seconds. So its average output current is 2.5mA. The capacity of the lithium polymer battery is determined by the pulse current. A 160mAh is selected for the reference design to support the almost 1C discharge current.

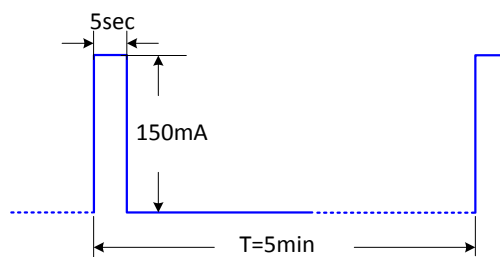


Figure 9: Load Current

3.1 Waveform at Alkaline Battery Running Low

Considering the worst condition when the alkaline is nearly out of charge, the operating waveform is shown in Figure 10. When the load current is zero, the output voltage of the alkaline battery V_{IN} is about 0.85V and its output current is around 20mA to charge the lithium polymer battery.

When the load current increases to 150mA, the lithium polymer battery voltage drops about 0.1V because of its internal effective resistor and battery protection circuit resistor. So the TPS61220 output current increase by $0.1V/40\Omega = 2.5mA$ and its input current I_{IN} increases by 20mA, which causes the alkaline battery voltage drop down about 87mV. The internal effect resistor of the alkaline battery can be calculated by $87mV/20mA$, which is around 4ohm.

This large internal effective resistor limits the alkaline battery output current capability. So normally it has to be replaced by a new one. But with the help of the lithium polymer battery to buffer the pulse current, the alkaline battery keeps operating and its lifetime can be extended.

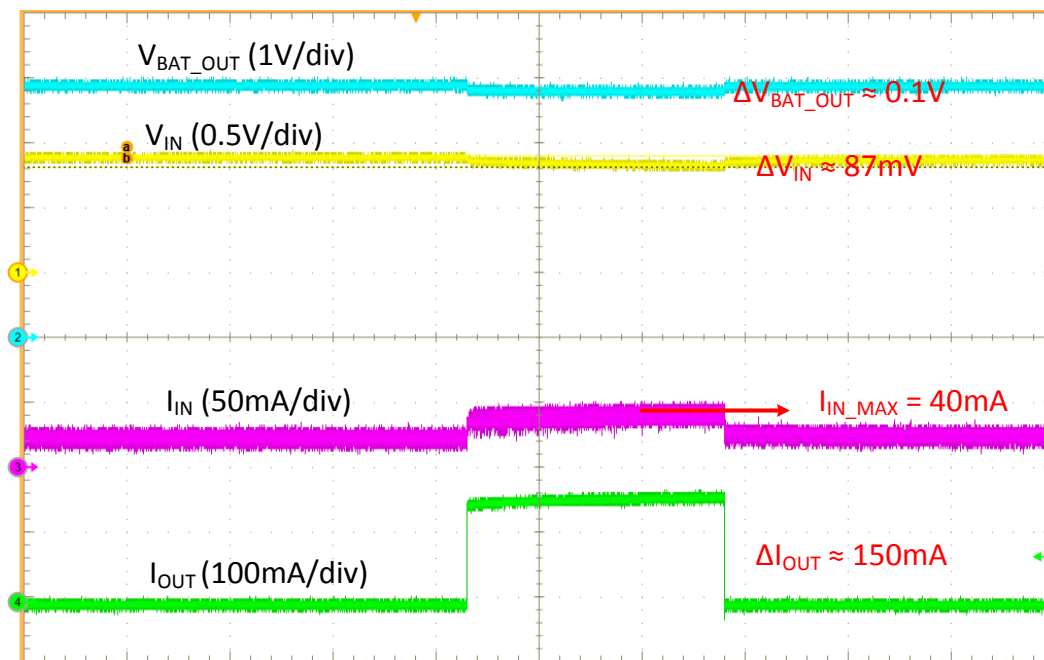


Figure 10: Operating Waveform When The Alkaline is Running Low

3.2 Backup Power at V_{IN} lower than $UVLO$

The setup of test condition is the same as in Figure 8. Instead of the alkaline battery, a power supply with output voltage smaller than 0.5V is used as input.

The test result is shown in Figure 11. As the V_{IN} is smaller than $UVLO$, The TPS61220 shuts down and its input current I_{IN} is zero. The lithium polymer battery keeps powering the load and stabilizes the output voltage of the reference design V_{BAT_OUT} until it is also out of charge.

As the average load current is 2.5mA, the 160mAh lithium polymer battery can support the load system to operate several tens of hours until the bad alkaline battery is replaced.

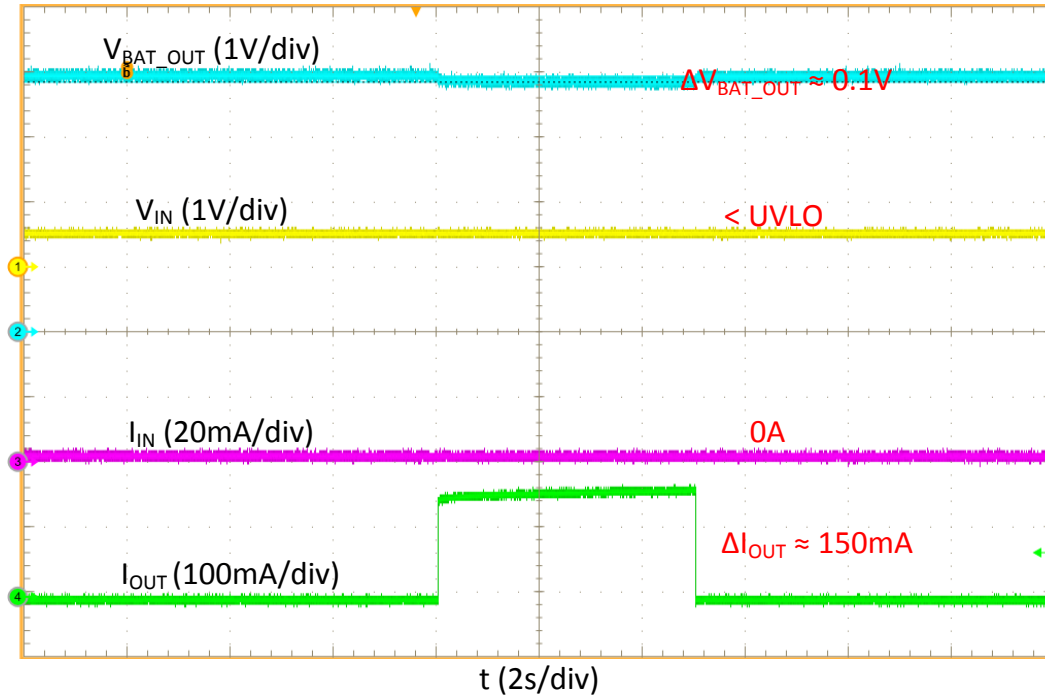


Figure 11: Test Result at The Alkaline Battery Output of Charge

3.3 Lithium Polymer Battery charging

The Figure 12 shows test result of the condition that the lithium polymer battery is recharged from 3.2V when a fresh alkaline battery is inserted. The lithium polymer voltage slowly goes up from 3.2V to 3.6V, and it would reach 4V finally in no load condition. The alkaline battery output voltage is 1.6V at beginning and down to 1.5V during being discharged. The TPS61220 input current and the output current is determined by the 40Ω current limit resistor and the lithium polymer battery voltage V_{BAT_OUT} , the higher V_{BAT_OUT} , the smaller current value. The TPS61220 output current is equal to the sum of load current, which is about 2.5mA, and lithium polymer battery charging current.

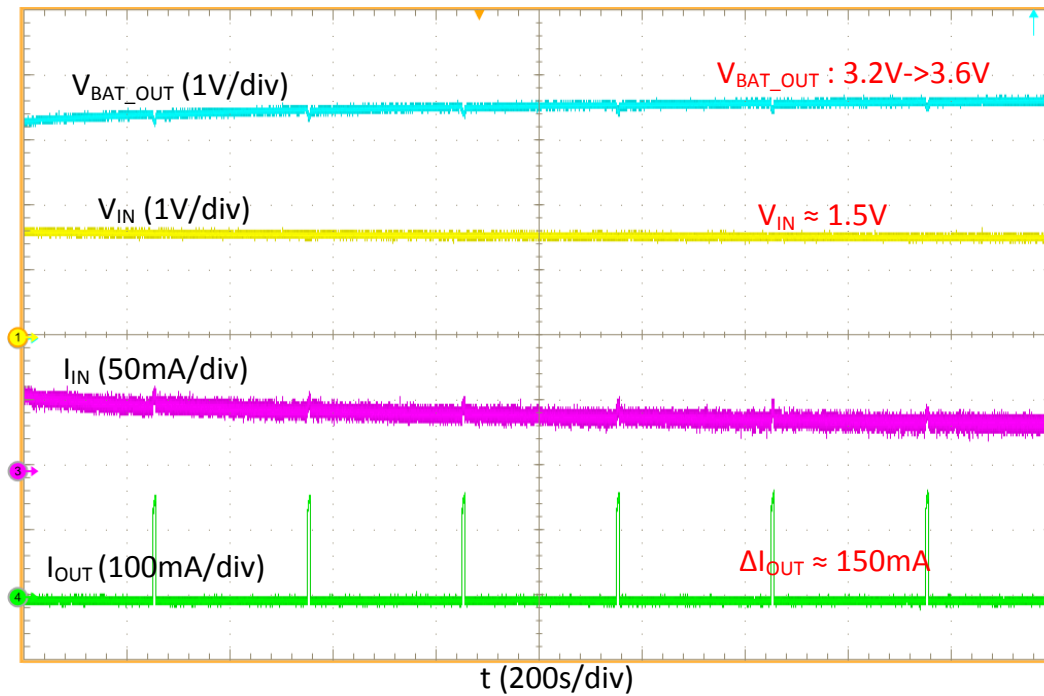


Figure 12: The Lithium Battery Voltage is Charged by The Alkaline Battery

4 Summary

An alkaline battery and low input voltage boost converter power circuit combined with a lithium polymer battery for the pulse load system brings following advantages:

1. Extend the alkaline battery lifetime because of the low current requirement.
2. Uninterrupted power supply for the important load when the alkaline battery is output of charge.
3. Low output current capability boost converter can be used.

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