Application Report
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Power-Path Li-Ion Charger Selection

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ABSTRACT

Texas Instruments offers three families of linear power-path Li-ion battery chargers — bq2403x, bq24070/1, and bq24072-5, which perform the same basic function of powering the system while independently charging a single Li-ion/polymer cell. The two power-path technologies that are implemented are dynamic power management (DPM) and dynamic power-path management (DPPM). DPM is an input-current-based control and DPPM is an output-voltage-based control. Feature differences are examined so that users can select the most applicable integrated circuit for their design.

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1 Introduction

Power-path chargers use the input source to power the system and charge the battery. If the input source is removed, then the battery pack is automatically connected to the system. Table 1 shows the comparison of the three families of battery chargers. The bq2403x family has five spins but only one column is shown; these integrated circuits (IC) have only a few key differences that are explained in the text. The bq24070/1 and bq24072-5 families have the complete IC offerings shown. The top portion of Table 1 shows features that are the same whereas the lower portion shows features that are implemented differently or have features unique to that IC.

Table 1. Comparison of the Three Families

FEATURE	bq2403x	bq24070	bq24071	bq24072	bq24073	bq24074	bq24075
Power Path	Yes	Yes	Yes	Yes	Yes	Yes	Yes
USB 100, 500	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prog Timer with disable	Yes	Yes	Yes	Yes	Yes	Yes	Yes
THERMAL REG	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Inputs	Dual	Single	Single	Single	Single	Single	Single
Input Voltage	18 V	18 V	18 V	28 V	28 V	28 V	28 V
OVP	'5 only	No	No	Yes (6.5 V)	Yes (6.5 V)	Yes (10.5 V)	Yes (6.5 V)
VIN-Low Loop	No	No	No	Yes	Yes	Yes	Yes
DPM I_{LIM} Loop	USB Only	USB Only	USB Only	Yes	Yes	Yes	Yes
I-chg	1.5 A	1.5 A	1.5 A	1 A	1 A	1 A	1 A
OUT Pin Voltage	4.4 V or 6 V	4.4 V	6 V	VBAT + 200 mV	4.4 V	4.4 V	5.5 V
DPPM Loop	Program	Program	Program	Fixed	Fixed	Fixed	4.4V
ITERM	Fixed	Fixed	Fixed	Fixed	Fixed	Program	Fixed
Termination Disable	Yes	Yes	Yes	Yes	Yes	Yes	No
CE Feature	I_{IN} EN/DIS	I_{IN} EN/DIS	I_{IN} EN/DIS	Chg EN/DIS	Chg EN/DIS	Chg EN/DIS	Chg EN/DIS
EN1/EN2-PSEL/CE/ISET2	PSEL/CE ISET2	MODE/CE ISET2	MODE/CE ISET2	EN1/EN2 I_{IN} Control	EN1/EN2 I_{IN} Control	EN1/EN2 I_{IN} Control	EN1/EN2 I_{IN} Control
SYS-OFF	No	No	No	No	No	No	Yes
Package	3.5X4.5 QFN-20	3.5X4.5 QFN-20	3.5X4.5 QFN-20	3X3 QFN-16	3X3QFN-16	3X3 FN-16	3X3 QFN-16

This document focuses on the shaded grey area.

- **Single- or Dual-Input Sources – Adapter (VDC) or USB**
  The bq2403x family has two independent inputs so that an adapter and USB input can be attached at the same time. The other families have one input, but the chip can be programmed by an external pin to indicate which source is connected to the single input.
- **Input Voltage Maximum Rating for AC or IN Pin**
  The bq24072-5 ICs have a higher IN pin rating (28 V versus 18 V) and can be beneficial if designing for protection against higher transient voltages. Higher input voltages (less than maximum) often cause the input to shut off or possibly operate in a limited capacity.
- **Overvoltage Protection (OVP) – IC does not deliver current if the input is greater than the OVP level.**
  The bq24072-5 family has OVP; the only other IC that has OVP is the bq24035.
- **V_{IN-LOW} LOOP – Input current is restricted if Vin falls to V_{IN-LOW} threshold.**
  The bq24072-5 family of ICs implements this feature if the USB mode is selected, EN2=0.
- **DPM_I_{LIM} Loop – Limiting input current to a fixed or programmed threshold**
  The bq2403x and bq24070/1 families have an internal 100-mA to 500-mA USB input current limit and a ~2.5-A “AC” input current limit. The bq24072-5 family has a programmable I_{IN} current limit (I_{LIM}) when in adapter mode and a 100-mA to 500-mA limit when in USB mode. If I_{LIM} is actively restricting current, the OUT voltage drops to the DPPM threshold where the charging current is reduced.
- **Input Current Rating**
  The bq2403x and bq24070/1 families have a larger die and power-pad area, which allows more heat dissipation, and thereby a higher current can be used than the bq24072-5 family, assuming a similar PCB layout.

- **OUT Pin Regulation Voltage**
  The bq24072's OUT tracks the battery voltage plus 200 mV until the output drops to 3.4 V and then stays there for battery voltages less than 3.2 V; all other spins are regulated at 4.4 V or 6 V as per Table 1. The bq24035 regulates at 6 V, but has OVP set at approximately 6.4 V, so that this part is typically used as an input switch, with an input voltage closer to 5 V, rather than an LDO output.
- **DPPM Loop – Limiting CHG current when OUT voltage drops to DPPM threshold**
  The bq2403x and bq24070/1 families have a programmable DPPM threshold, whereas the bq24072-5 family has fixed thresholds. The fixed internal thresholds are ratiometric and are therefore more accurate than the externally programmed thresholds, thus minimizing any issues with accuracy.
- **I_{TERM} – Charge Termination Threshold**
  The bq24074 has a programmable termination threshold via an external resistor. All the other spins have a fixed 10% of fast charge termination threshold.
- **TD (Termination Disable) – Enables or Disables Safety Timers**
  The bq24072-5 family has a dedicated pin, the TD pin, whereby termination of the safety timers can be disabled independently. The bq2403x and bq24070/1 families have only a TMR pin, which if pulled to the LDO voltage, disables both the timers and termination.
- **CE – Chip or Charge Enable/Disable**
  The bq2403x and bq24070/1 families implement the CE function as a chip disable feature to disconnect the source from the system and battery. This can be used as an adapter (AC) or USB suspend. If the chip is disabled, the battery FET automatically turns on and connects the BAT pin to the OUT pin. The bq24072-5 family defines the $\overline{CE}$ pin as a charge enable control. If the $\overline{CE}$ pin is high, the charge is disabled but the IN pin is still powering the OUT pin. This pin is not used as a USB suspend (see EN1/EN2).
- **EN1/EN2 – Input Current Control**
  The bq24072-5 family implements four functions using the EN1/EN2 pins, 100 mA, 500 mA, I_{LIM} control, and suspend. The bq2403x and bq24070/1 families use the PSEL/MODE pin (adapter or USB), CE (Chip Enable) pin, and ISET2 (100-mA to 500-mA) pin to control similar features.
- **System Off – Turns Off the BAT-to-OUT FET Internal to the IC**
  The bq24075 is the only IC to offer the feature using an external pin to turn off the internal BAT-to-OUT FET. A high on this pin disables the FET.
- **Package**
  The bq2403x and bq24070/1 families of ICs are packaged in a 3,5 × 4,5-mm QFN package. The bq24072-5 family of ICs is packaged in a 3 × 3-mm QFN package.

2 Detailed Discussion of the DPPM Power-Path Technology

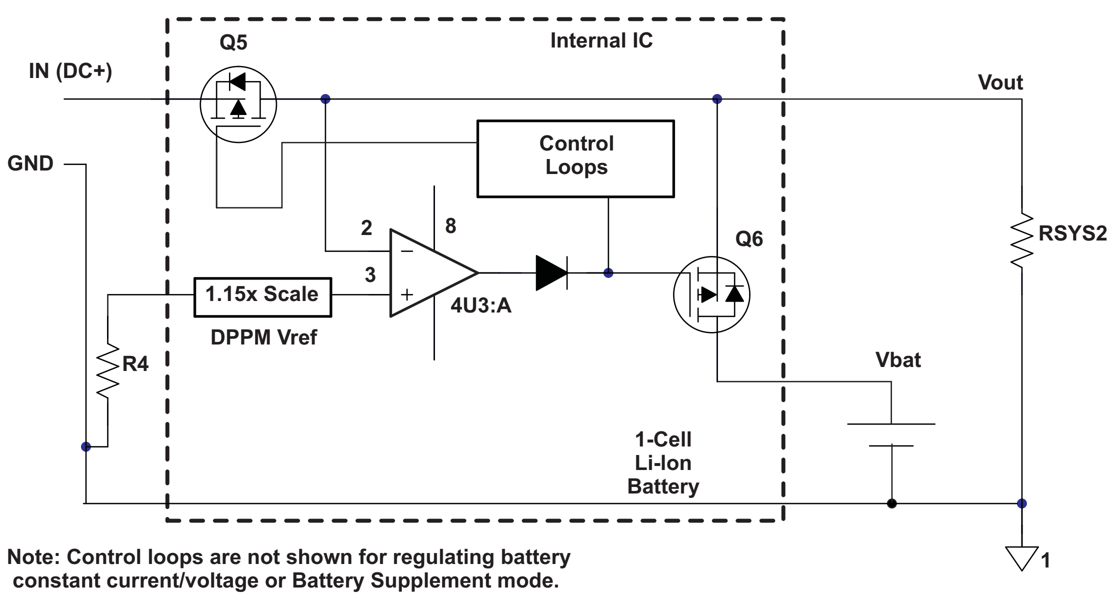

Figure 1. DPPM – Manages Battery Current Based on Output Voltage

Dynamic power-path management (DPPM) is a current management routine based on the system voltage, where if the system voltage drops to a preprogrammed (or fixed) threshold, due to loss of power or a current-limit threshold, the battery charging current is sufficiently reduced to prevent any further drop in the system voltage.

The advantages of DPPM are:

- Allows selection of a lower cost adapter.
- Better protection from system crashes due to low-power adapters and power grid brown-outs.
- Better efficiency than running off battery.

A lower cost adapter can be chosen based on the average load (average system load, 0.5 A plus fast-charge load 1 A) instead of a peak load. If a peak system load requires an additional 0.75 A over the average load, then the charging current is reduced by this amount during the peak load transient. The DPPM system voltage-based routine detects a current-limited adapter or brown-out condition when the system voltage drops to the detection threshold. Reducing the charging current helps keep the system from crashing as long as the system load current alone does not exceed the input current limit.

Note that this assumes that the battery is absent or fully depleted; otherwise, the battery provides the necessary power to the system.

The efficiency is best when there is less voltage drop from the input to the system output. During DPPM, if the DPPM threshold is set above the battery voltage, the efficiency is higher than the configuration where the threshold is set below the battery and the output drops to the battery voltage. For a high threshold setting, DPPM mode delivers a slightly lower efficiency than the DPM routine. If DPPM is entered a low percentage of the time, then the efficiencies results between DPPM and DPM are similar. Charging efficiency is only a concern if the product temperature has a heat issue. The size of the BAT FET is more of a concern for run time and is often larger (lower resistance) in a DPPM design because it requires two power FETs instead of three.

The disadvantages of DPPM are:

- System output voltage transients may affect sensitive circuits like audio amplifiers.
- Slightly lower charging efficiency than DPM.

The system output voltage drops due to the system and charging load exceeding the current limit of the input sources.

3 Detailed Discussion of the DPM and the Hybrid DPM/DPPM Power-Path Technology

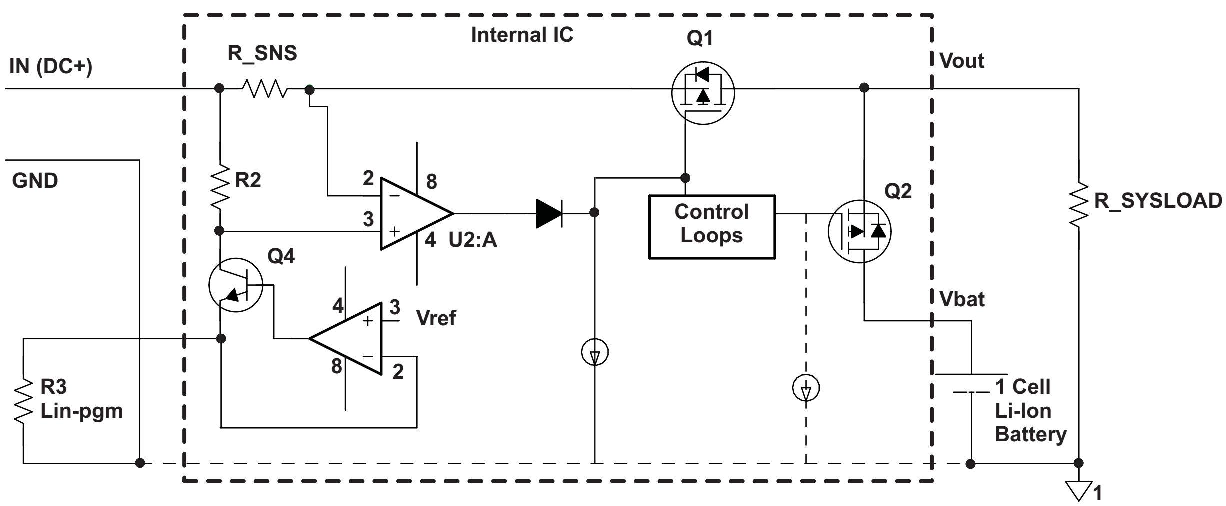

Figure 2. bq24072-5 DPM/DPPM Hybrid Topology

Figure 2 show a hybrid DPM/DPPM topology. The pure DPM topology monitors input current and if the defined current threshold is reached, due to the system and charger loads, the charge current is reduced to offset any further increase in system loading. The hybrid DPM/DPPM topology provides the same protection for the adapter by monitoring input current, but achieves the result in a slightly different way. If the system load plus the battery load current reach the input current threshold, the input pass FET, Q1, starts to turns off causing the OUT voltage to drop and hit the DPPM threshold and then the charge current is reduced. Due to the improved accuracies of the bq24072-5 series, the DPPM threshold is set 100 mV below the regulation voltage. The advantages of this topology are the same as the DPPM topology, including the advantages of the DPM topology, and improved efficiency due to a minimal output drop during DPPM/DPM. If this were a pure DPM topology, it would not have protection from brown-outs and lower current-rated adapters, whereas the hybrid topology does.

For new designs, the bq24072-5 is the preferred IC because it offers more features that other ICs. The bq2403x and bq24070/1 families are better for high-power applications where the bq24072-5 family does not meet those requirements. The bq2403x family offers dual input.

4 bq24074 Charger Design Example

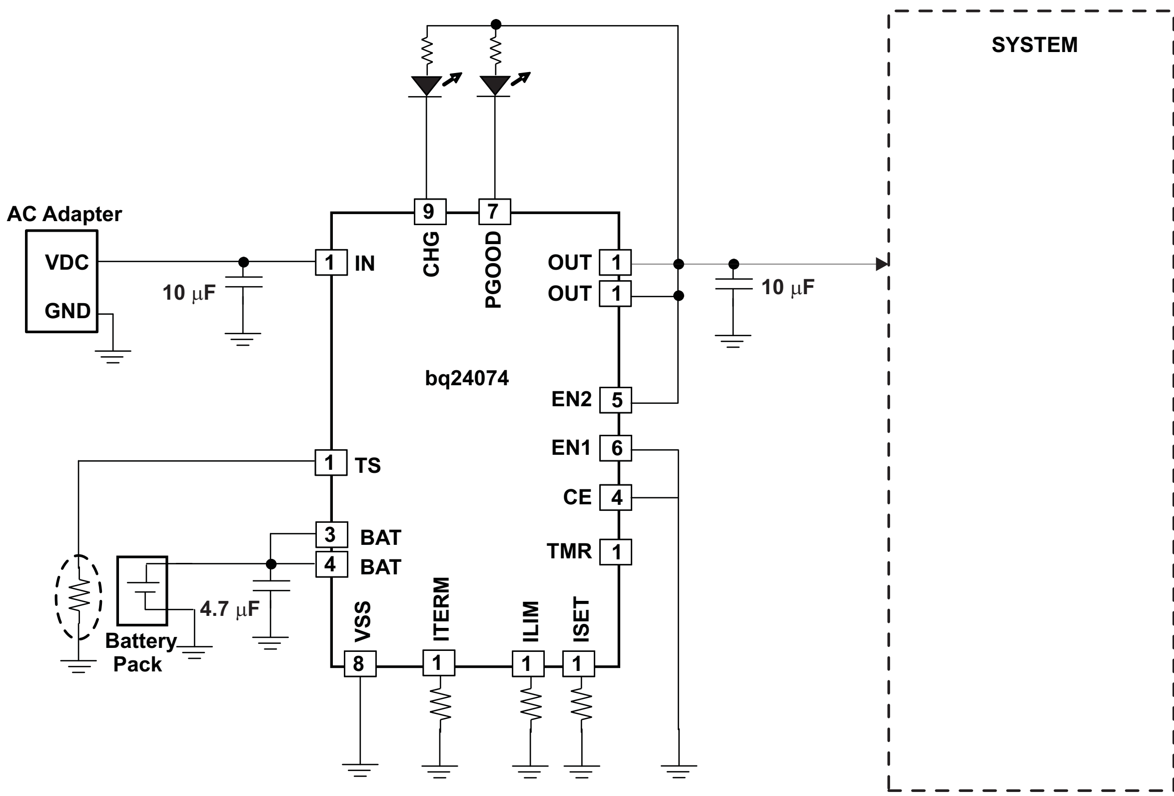

Figure 3. bq24074 Charger Design

4.1 Requirements

- Supply voltage = 5 V
- Fast-charge current of approximately 900 mA; ISET – pin 16
- Input current limit = 2.2 A; ILIM – pin 12
- Termination current threshold = 120 mA; ITERM – pin 15
- Safety timer duration, fast-charge = 6.25 hours; TMR – pin 14
- TS – battery temperature sense = 10k NTC (103AT)

4.2 Calculations

Program the Fast Charge Current, ISET:
$R_{ISET} = [K_{(ISET)} / I_{(CHG)}]$
from electrical characteristics table. . . $K_{(ISET)} = 890$

R_{ISET} = [890 AΩ/0.80 A] = 1.113 kΩ
Selecting the closest standard value, use a 1.13-kΩ resistor between ISET (pin 16) and Vss.

Program the Input Current Limit, I_{LIM}:
R_{ILIM} = [$K_{(ILIM)}$ / $I_{(IN\_MAX)}$]
from electrical characteristics table. . . $K_{(ILIM)}$ = 1550 AΩ
R_{ISET} = [1550 AΩ/1.3 A] = 1.192 kΩ
Selecting the closest standard value, use a 1.18-kΩ resistor between ILIM (pin 12) and Vss.

Program the Termination Current Threshold, ITERM:
R_{ITERM} = [$I_{(TERM)} \times R_{(ISET)}$/0.030]
from above . . . $R_{(ISET)}$ = 1.13 kΩ
R_{ITERM} = [120 mA × 1.13k/0.030] = 4.52 kΩ
Selecting the closest standard value, use a 4.53-kΩ resistor between ITERM (pin 15) and Vss.
Note that when in USB 100-mA mode, the termination threshold is one-third the normal threshold.

Program 6.25-hour Fast-Charge Safety Timer, TMR:
$R_{(TMR)}$ = [$t_{(MAXCHG)}$ / (10 × $K_{(TMR)}$)]
from the electrical characteristics table. . . $K_{(TMR)}$ = 48 s/kΩ
$R_{(TMR)}$ = [6.25 hr × 3600 s/hr / (10 (48 s/kΩ)] = 48.87 kΩ
Selecting the closest standard value, use a 46.4-kΩ resistor between TMR (pin 2) and Vss.

TS Function:

Use a 10k NTC thermistor in the battery pack (103AT).

To disable the temp sense function, use a fixed 10-kΩ resistor between the TS (pin 1) and Vss

CHG and PG:

LED Status: connect a 1.5-kΩ resistor in series with a LED between the OUT pin and the CHG pin and PG pin.

Processor Monitoring Status: connect a pullup between the processor’s power rail and the CHG pin and PG pin.