Dynamic power management for faster, more efficient battery charging

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Introduction

With the fast-growing demand for emerging portable devices such as tablets and smartphones, there are many new challenges in improving battery-operated system performance. The battery-management system must be intelligent to support different types of adapters and battery chemistries and must provide fast charging with high efficiency. At the same time, it is important to provide a good user experience with instant turn-on of the system, longer battery run time, and fast charging. This article discusses how to achieve fast battery charging and improve battery-charging performance with dynamic power management (DPM). DPM helps to avoid system crashes and maximizes the power available from the adapter. It can be based on input current or input voltage, or combined with a battery-supplement mode. This article also discusses critical design considerations for extending battery run time.

The lithium-ion (Li-Ion) battery is desirable for the ever-growing power need in portable devices because it has very high energy density. Nowadays, it is common for a 10-inch tablet to include a battery pack with 6- to 10-Ah capacity to support a long run time. With the high-capacity battery, it is critical for the portable device to have fast and efficient charging for a good user experience. Additionally, tablets require other features such as superior thermal performance and instant turn-on, even with a deeply discharged battery. These requirements present a few technical challenges. One is how to maximize available power from the power source to efficiently and quickly charge the battery —while not crashing the power source. Another is how to charge a deeply discharged battery while simultaneously operating the system. Last is how to extend the battery run time and improve thermal performance.

Dynamic power management (DPM)

How can available power be maximized to charge the battery quickly and efficiently? Every power source has its output current, or power limit. For example, the maximum output current is limited to 500 mA from a high-speed USB (USB 2.0) port, and up to 900 mA from a SuperSpeed USB (USB 3.0) port. The power source can crash if the system's power demand exceeds the power available from the power source. When the battery is being charged, how can a power-source crash be prevented while the power output is being maximized? The following discussion presents three control methods: DPM based on input current, DPM based on input voltage, and DPM used with a battery-supplement mode.
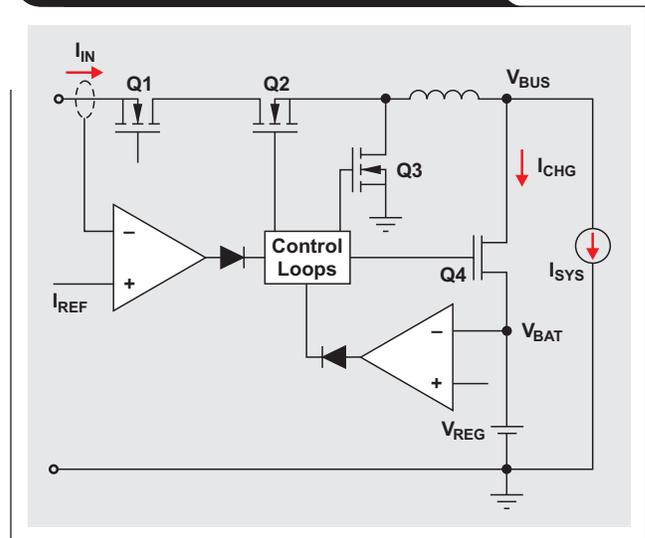
DPM based on input current

Figure 1 shows a high-efficiency switch-mode charger with DPM controls. MOSFETs Q2 and Q3 and inductor L make up a synchronous switching buck-based battery charger. Using a buck converter ensures that the adapter's input power is efficiently converted to achieve the fastest battery charging. MOSFET Q1 is used as a battery reverse-blocking MOSFET for preventing leakage from the battery to the input through the body diode of MOSFET Q2. It also is used as an input-current sensor to monitor the adapter current.

MOSFET Q4 is used to actively monitor and control the battery-charging current to achieve DPM. When the input power is sufficient to support both the system load and battery charging, the battery is charged with the desired charge-current value of I_{CHG}. If the system load (I_{SYS}) is suddenly increased and its total adapter current reaches the current-limit setting (I_{REF}), the input-current regulation loop actively regulates and maintains the input current at the predefined I_{REF} input reference current. This is achieved by reducing the charge current while giving higher priority to powering the system so it can reach its highest performance. Therefore, the input power is always maximized without crashing the input-power source, while the available power is dynamically shared between the system and battery charging.

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DPM based on input voltage

If a third-party power source is plugged into a system that cannot identify its current limit, it is difficult to use DPM based on limiting the input current. Instead, DPM is based on the input voltage (Figure 2). Resistor dividers R1 and R2 are used to sense the input voltage and are fed into the error amplifier of the input-voltage regulation loop. Similarly, if the system load is increased, causing the input current to exceed the adapter's current limit, the adapter voltage starts to decrease and eventually reaches the pre-defined minimum input voltage. The input-voltage regulation loop is activated to maintain the input voltage at the predefined level. This is achieved by automatically reducing the charge current so that the total current drawn from the input-power source reaches its maximum value without crashing the source. Therefore, the system can track the adapter's maximum input current. The input-voltage regulation is designed to keep the voltage high enough to fully charge the battery. For example, the voltage can be set around 4.35 V to fully charge a single-cell, Li-Ion battery pack.

Battery-supplement mode

DPM based on input current or input voltage can draw the maximum power from the adapter without crashing it. For portable devices such as smartphones and tablets, the system load is usually dynamic with a high pulsating current. What happens if the pulsating system's peak power is higher than the input power, even when the charge current is already reduced to zero? The input-power source could crash without active control.

One solution is to increase the adapter's power rating, but this increases the adapter's size and cost. Another solution is to temporarily have the battery provide additional power to the system by turning the MOSFET Q4 on to discharge the battery instead of charging it. Combining the DPM control and the battery-supplement mode allows the adapter to be optimized to support the average power instead of the maximum peak system power, reducing the cost and achieving the smallest solution size.

Design considerations for improving system performance

Portable systems such as tablets and smartphones require instant turn-on to provide a good user experience. This means that whether the battery is fully charged or deeply discharged, the system will turn on instantly when an adapter is plugged in.

Figure 2. DPM based on input voltage
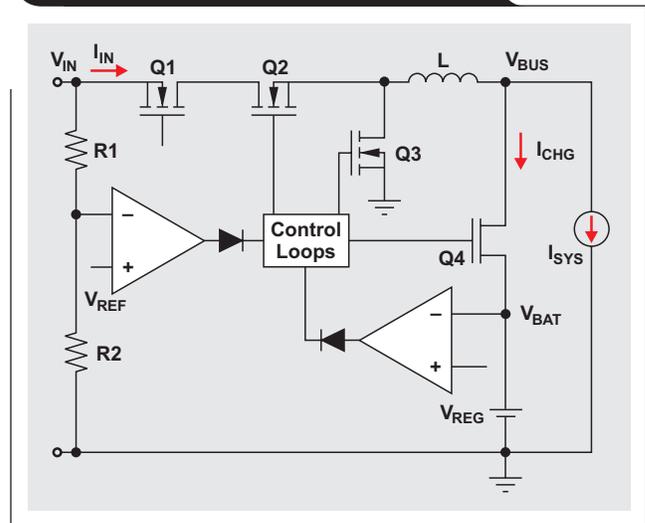
As an example, suppose that a one-cell Li-Ion battery is used for the systems in Figures 1 and 2. If the battery is directly connected to the system without MOSFET Q4, the system bus voltage (V_{BUS}) is the same as the battery voltage. A deeply discharged battery with less than 3 V may prevent system turn-on. The user may have to wait until the battery is charged to 3.4 V before turning on the system. In order to support instant turn-on, MOSFET Q4 is added to operate in linear mode to maintain the minimum system-operation voltage while simultaneously charging a deeply discharged battery. The minimum system voltage is regulated by the switching converter, and the charge current from Q4 is regulated with a linear control loop. Once the battery voltage reaches the minimum system voltage, MOSFET Q4 is fully turned on. Its charge current is then regulated by the duty cycle of the synchronous buck converter. So the system voltage is always maintained between the minimum system-operation voltage and the maximum battery voltage for powering the system.

In a 5-V USB charging system, all series resistance between the power source and the battery contributes to charging efficiency. This resistance in the charging path consists of the ON resistance of FETs Q1, Q2, and Q4 and about 250 mΩ from the USB cable. It is not unusual to have a 4.5-V charger input after a cable voltage drop. Therefore, it is critical to design a charger with the lowest possible

FET ON resistance to minimize charging time. Figure 3 compares the charging time of a design using the Texas Instruments bq24190 USB/adapter charger and an alternative design having an extra 80 mΩ in the charging path. It can be seen that, with a 4.5-V input voltage, the charging time of the bq24190 design is reduced by 20% compared with the other design.

Extending battery run time

Of course, the higher the battery capacity, the longer is the battery run time. For a single-cell operating system that usually requires a 3.3-V output, the typical minimum system voltage is around 3.4 V. If the ON resistance of MOSFET Q4 is 50 mΩ, and the battery-discharge current is 3 A, the battery cutoff voltage is 3.55 V. This means that over 15% of the battery capacity is unused. In order to maximize the battery run time, the MOSFET Q4's ON resistance must be as small as possible. For instance, with an ON resistance of 10 mΩ and the same peak battery-discharge current of 3 A, the battery cutoff voltage will be 3.43 V. This provides 10% more battery capacity than with an ON resistance of 50 mΩ.

Figure 4 shows an example of a high-efficiency, single-cell I²C battery charger with integrated MOSFETs. This charger supports both USB and AC adapter inputs for tablets and portable media devices. All four power MOSFETs are integrated, while MOSFETs Q1 and Q4 are used to

sense the input current and battery-charge current, further minimizing the system's solution size. This charger can distinguish between a USB port and an adapter to quickly set the correct input-current limit. Additionally, the charger can operate as a stand-alone charger with internal default charge current, charge voltage, a safety timer, and input-current limits—even when the system is turned off. The charger also has a USB On-the-Go (OTG) function, operating in boost mode to provide a 5-V, 1.3-A output at the USB input from the battery.

Figure 3. Effect of high ON resistance in the charging path

Figure 4. High-efficiency, 4-A I²C switching charger with DPM

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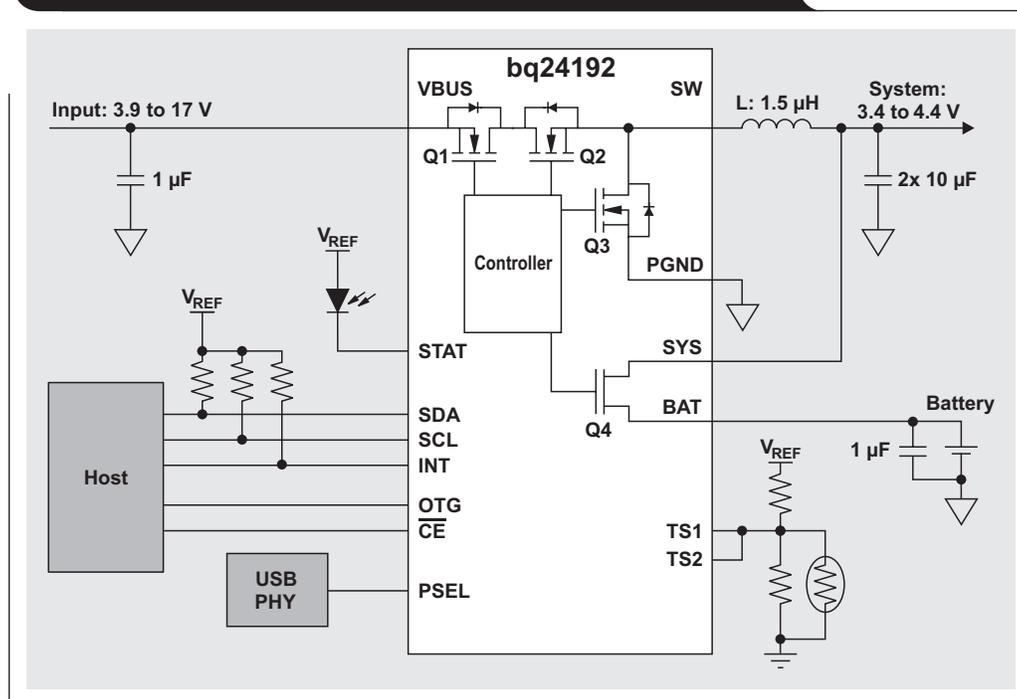
Thermal performance

Thermal performance is critical for portable devices with a very thin profile because users can easily feel the heat dissipated from the printed circuit board. This heat is due to components that consume a lot of power, such as the battery charger. To combat this, a high-efficiency charger and a good layout are very important. To further improve the thermal performance, a thermal-regulation loop is available in the bq2419x family. It maintains the maximum junction temperature by reducing the charge current once the device reaches the predefined junction temperature. Figure 5 shows the measured battery-charging efficiency in a bq24190 design. Up to 94% efficiency can be achieved with a 5-V USB input. With a 9-V input and a 4-A charge current, there is only a 32°C temperature rise.

Conclusion

This article has shown that DPM based on either input current or input voltage can be used to power portable devices, providing instant system turn-on while simultaneously charging the battery. It has also been shown that adding a battery-supplement mode is critical for optimizing power-system performance. Other design considerations have also been discussed, such as instant turn-on with a depleted battery, battery run time, charging-path resistance, and thermal performance.

Figure 5. Measured battery-charging efficiency at different charge currents
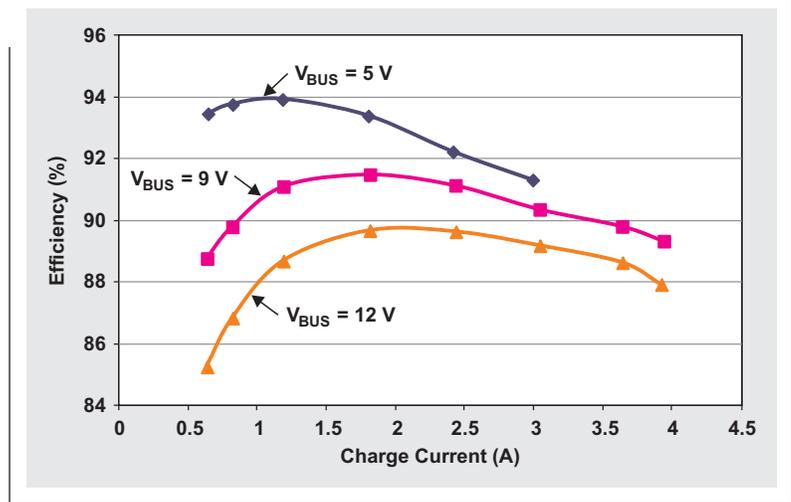
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