Turbo-boost charger supports CPU turbo mode

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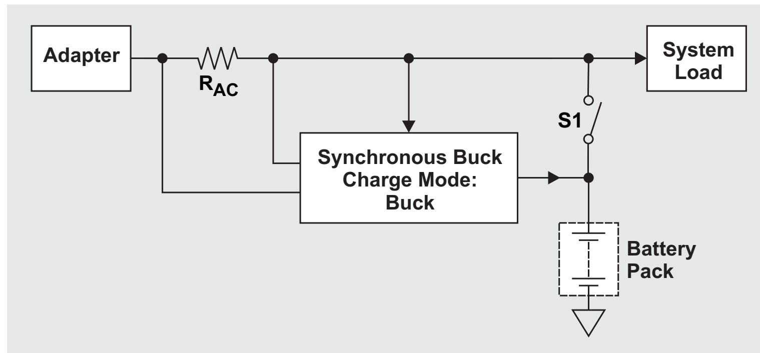
Introduction

To continuously improve a CPU's dynamic performance for fast processing of multiple complicated tasks in mobile computers, it is essential to increase the CPU frequency with full utilization of the CPU's thermal capability in a short time period. This could cause the total power required by the system to exceed the power delivered from a power source like an AC adapter, which may result in crashing the adapter. One possible solution is to increase the adapter's power rating, but at a higher cost. This article discusses the turbo-boost charger, which allows the adapter and battery to power the system simultaneously to meet instantaneous and excessive power demands from a notebook computer system operating in CPU turbo mode.

Figure 1. Adapter and battery-charger system



In traditional mobile computer systems, an AC adapter provides the power, and any power not needed by the system is used to charge the battery. When an AC adapter is not available, the battery provides power to the system by turning on switch S1 (see Figure 1). The adapter can be used to power the system and charge the battery simultaneously, which may require it to have a high power rating, increasing both its size and its cost without active control. Dynamic power management (DPM) typically is used to accurately monitor the total power drawn from the adapter, which gives high priority to powering the system.

Once the adapter's power limit is reached, the DPM control system regulates the input current (power) by reducing the charge current, providing power directly from the adapter to the system without power conversion for optimum efficiency. With the heaviest system load, all the adapter power is used to power the system without charging the battery at all. Therefore, the main design criterion is to make sure that the adapter's power rating is high enough to support peak CPU power and other system power.

To meet the increasing demand for improved system performance in processing complicated tasks fast with multiple CPU cores and enhanced graphics processor units (GPUs), Intel developed its turbo-boost technology in the Sandy Bridge processors. This technology allows processors to burst their power above the thermal design power (TDP) for a short time period in the range from a few tens of milliseconds to tens of seconds. However, an AC adapter is designed to provide the power just above the demand from the processors and platform at a TDP level considering the design tolerance. When a charger system detects that the adapter has reached its input power rating after its charge current has been reduced to zero through DPM, the simplest way to avoid crashing the AC adapter is to achieve CPU throttling by reducing the CPU frequency, which compromises system performance. How can the CPU be operated faster at above the TDP level for a short time period without crashing the adapter or increasing its power rating?

Turbo-boost battery charger

When the total power required by the system load and battery charger reaches the adapter's power limit, DPM starts to reduce the battery's charge current. The battery charger stops charging, and its charge current is reduced to zero when the system load alone reaches the AC adapter's power limit. As the system continues to increase its load during the CPU turbo mode, the battery charger, which is usually a synchronous buck converter, is idle, as no remaining power is available to charge the battery. The synchronous buck converter is actually a bidirectional DC/DC converter that can operate in either buck or boost mode, depending on the operating conditions. If the battery has enough capacity, the battery charger can operate in boost mode to provide power to the system in addition to the power from the AC adapter. Figure 2 shows a block diagram of a turbo-boost battery charger.

When and how does the battery charger start to transition from buck charge mode to boost discharge mode? The system can enter CPU turbo mode at any time, and it is usually too late to inform the charger to initiate this transition through an SMBus. The charger should automatically detect which operating mode is needed. It is also critical that the system be designed to achieve a fast transition from buck to boost mode and vice versa. A DC/DC converter needs a soft-start time of a few hundred microseconds to a few milliseconds to minimize the inrush current. The adapter should have a strong overloading capability to support the whole system's peak power before the charger transitions into boost discharge mode. Most of the AC adapters currently available can hold their output voltage over a few milliseconds.

Figure 3 shows an application circuit for a turbo-boost battery charger supporting CPU turbo mode. The R_{AC} current-sense resistor is used to detect the AC adapter current for the DPM function and to determine whether the battery charger is operating in buck charge mode or boost discharge mode. Current-sense resistor R7 is used to sense the battery charge current programmed from the host through the SMBus based on the battery conditions. The total power drawn by both the charger and the system can be monitored through the I_{OUT} output, which is 20 times the voltage drop across sense resistor R_{AC} for achieving CPU throttling, if needed. Through SMBus control registers, the battery's boost discharge mode can be enabled or disabled based on the battery's state of charge and temperature conditions. In boost discharge mode, the circuit provides additional cycle-by-cycle current-limit protection by monitoring the voltage drop across the

Figure 2. Turbo-boost battery charger in CPU turbo mode

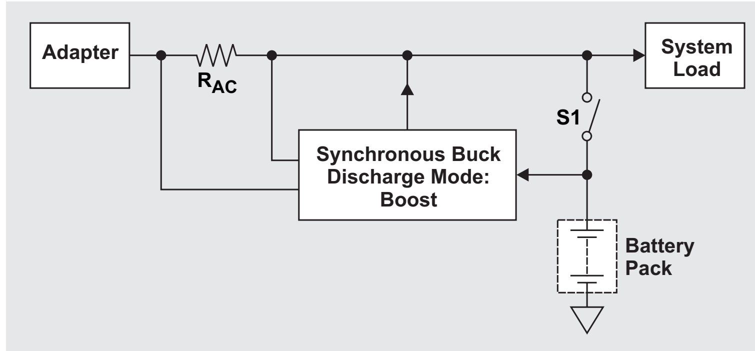
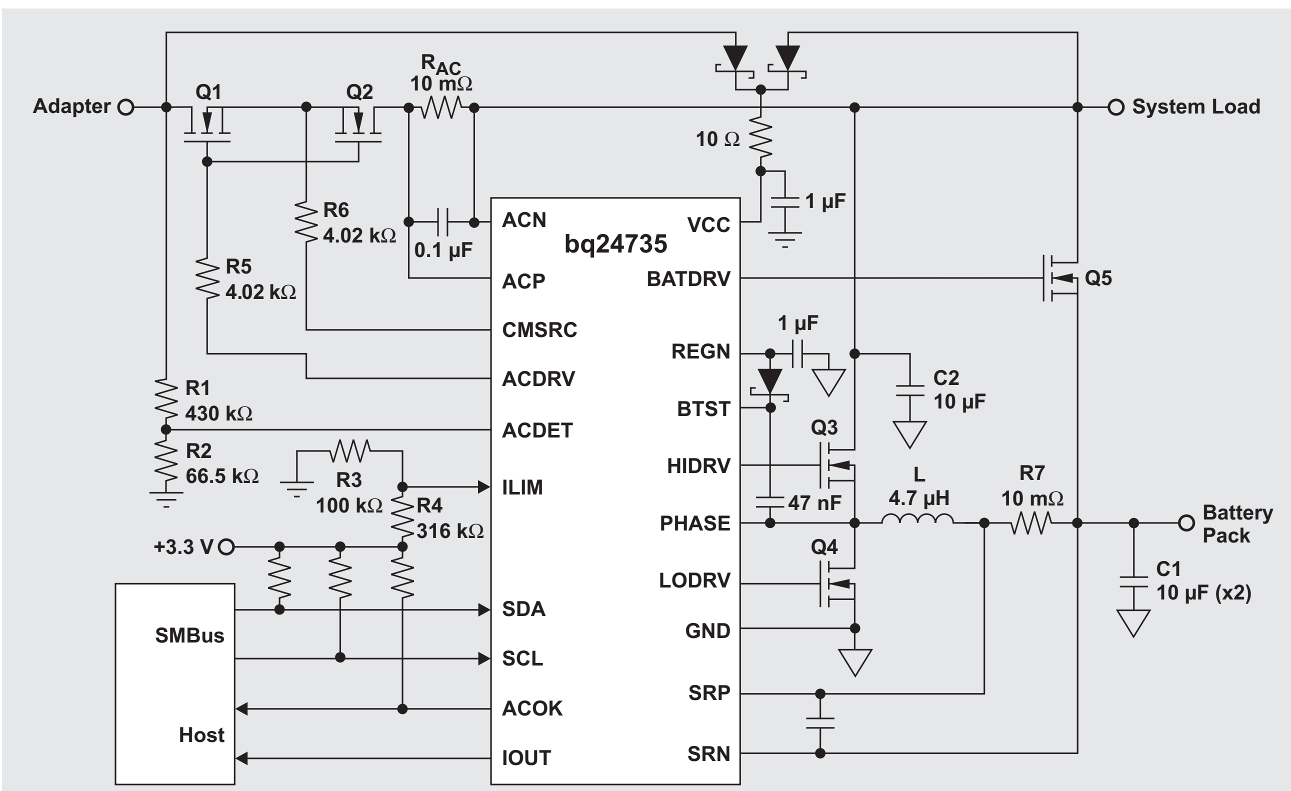


Figure 3. Application circuit for turbo-boost battery charger



low-side MOSFET, Q4. To achieve a small form factor for a notebook computer like Intel's Ultrabook™, the switching frequency can be programmed at 615, 750, or 885 kHz. This minimizes the inductor size and the number of output capacitors. To further reduce the number of external components, the charger's controller chip fully integrates the loop compensators for the charge current, the charge voltage, and the input-current regulation loops. The power-source selector MOSFET controller is also integrated in the charger. Furthermore, the charger system uses all n-channel MOSFETs for cost reduction instead of the p-channel power MOSFETs used in traditional charge solutions. Another benefit of this turbo-boost charger system is that it can be used for either function without changing the bill of materials. System designers can do a quick system-performance evaluation without additional hardware-design effort.

Figure 4 shows the switching waveforms that occur during the transition from buck charge mode to boost discharge mode. When the input current reaches the adapter's maximum power limit due to a system-load increase, the battery charger stops charging and the battery transitions into boost mode to provide additional power to the system.

Figure 5 shows the efficiency of the turbo-boost charger. It can be seen that over 94% efficiency is achieved for charging and discharging a 3-cell or 4-cell battery pack. If the battery is removed or the battery's remaining capacity is not high enough, it is necessary to throttle the CPU to avoid the adapter crash.

Now the battery can be discharged even when the adapter is connected. However, one possible concern is the battery cycle life. Since the boost discharge mode lasts from only tens of milliseconds to tens of seconds, the impact on battery cycle life will be minimal. Battery degradation is proportional to the battery-cell voltage; so the higher this voltage is, the faster the battery will degrade and the shorter its cycle life will be. Discharging the battery in the boost discharge mode results in a lower battery-cell voltage, reducing the degradation of the battery and lengthening its cycle life.

Figure 4. Waveforms between buck charge mode and boost discharge mode

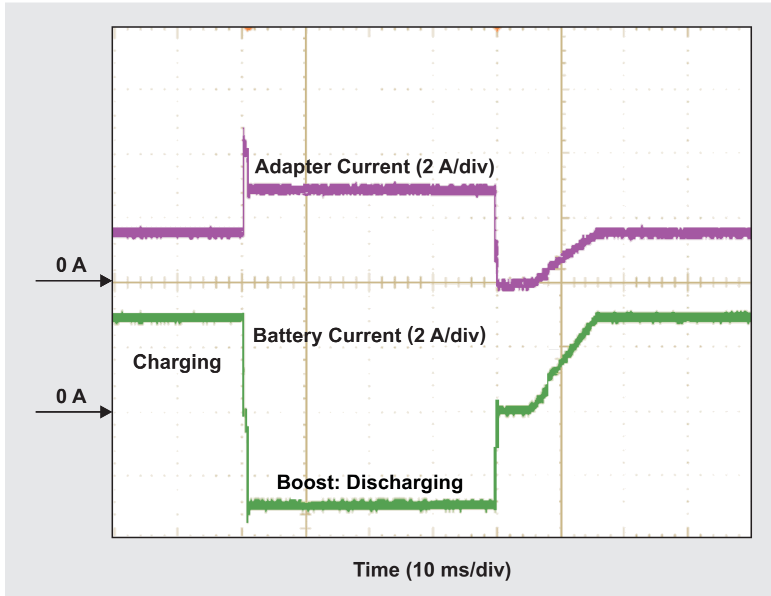
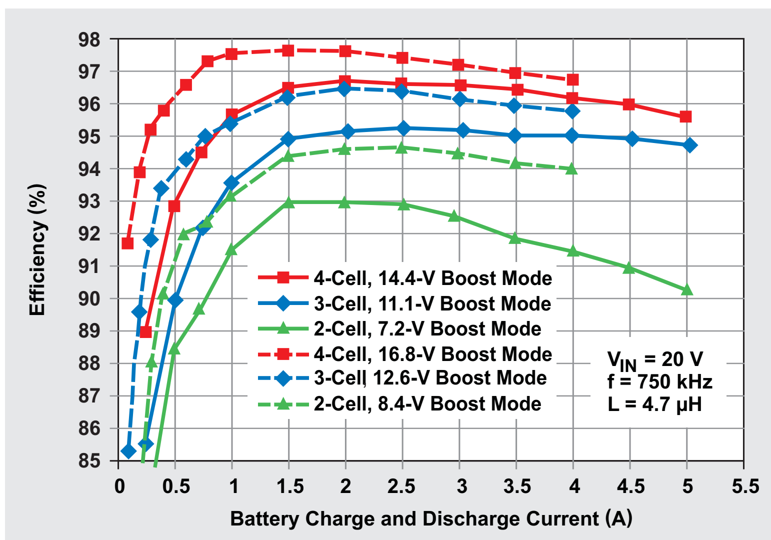


Figure 5. Efficiency of turbo-boost charger



Conclusion

A turbo-boost charger is a simple and cost-effective way for a battery to supplement AC adapter power for short periods when an AC adapter and battery simultaneously power the system. This topology supports CPU turbo mode while ensuring the lowest system cost without the need for upgrading to an AC adapter rated for peak system power. The test results show that the turbo-boost charger is a practical solution in real mobile-computer designs.

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