Combining buck-boost battery chargers and USB Type-C™ Power Delivery for maximum power density

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Buck-boost chargers deliver fast and cool charging for portable electronics. When combined with USB Type-C™ Power Delivery (PD), universal charging is made possible.

At a glance

This paper examines the benefits of combining USB Type-C PD and buck-boost charging for portable electronic designs.

1 **Why universal charging**

USB Type-C offers a realistic path to a universal adapter for easy charging on the go.

2 **Integrated components maximize power density**

Chargers that come with integrated components can help streamline overall solution size and reduce bill of materials while delivering high power.

3 **Implementing buck-boost charging**

Not all buck-boost chargers are the same, and design engineers must choose carefully for portable electronic designs.

The buck-boost charger has become increasingly popular in recent years given its ability to charge a battery from nearly any input source, regardless of whether the input voltage is higher or lower than the battery voltage.

Buck-boost charging has been widely used in personal electronic devices compatible with USB Type-C™ Power Delivery (USB PD) charging – because a fully integrated buck-boost charger that includes switching metal-oxide semiconductor field-effect transistors (MOSFETs), current-sensing circuitry and narrow VDC (NVDC) power path management can provide a fast charging solution with high power density. A buck-boost charger also integrates additional components in the USB PD charging system, such as load switches and DC/DC converters, to streamline system design, reduce bill-of-materials (BOM) cost and keep the overall solution size small.

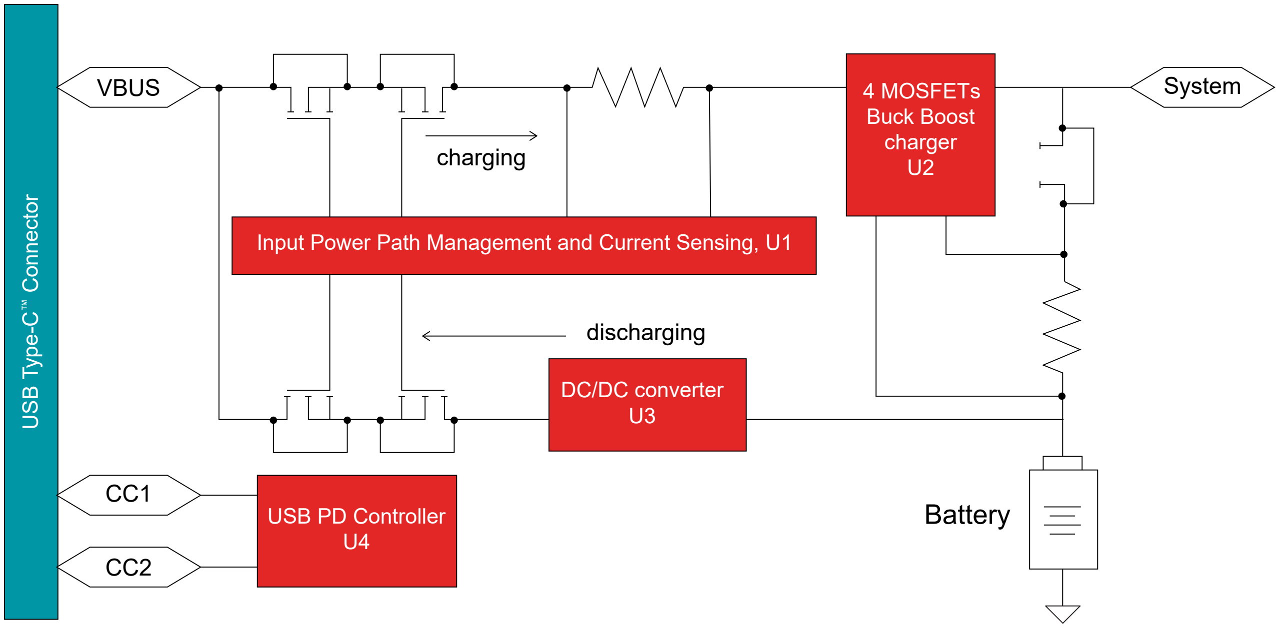

Figure 1. *Block diagram for a USB PD charging solution.*

Why universal charging

One critical benefit of the widespread adoption of USB Type-C is a realistic path to a universal adapter and corresponding e-waste reduction. Although the USB Type-C connector is unified, adapter power ratings and voltages still have large variations, including the legacy 5-V USB adapter and USB PD adapters capable of providing a voltage range from 5 V to 20 V. In addition, different portable devices might have different numbers of cell batteries inside. These variabilities in input voltage and battery voltage require a buck-boost topology for battery-charger integrated circuits (ICs).

Figure 1 shows a system block diagram for a USB PD charging solution. Through the CC1/CC2 pins, the USB PD controller identifies the adapter. After handshaking between the adapter and the USB PD controller, the unit managing the charging power path turns on back-to-back MOSFETs to pass the adapter voltage from VBUS to the input of the buck-boost charger. This unit (U1) also has to provide overvoltage and overcurrent protection by sensing the input voltage and current through the sensing resistor. The buck-boost charger requires four switching MOSFETs to step the input voltage up or down in order to charge the different battery voltages. In addition, the narrow VDC (NVDC) power path management and charging current sensing require one more MOSFET and another current-sensing resistor at the charger's output side.

On-the-go charging

In order to support the USB On-the-Go (OTG) specification, one DC/DC converter discharges the battery to build up a regulated voltage at VBUS and power external devices when the adapter is not present. If the USB Type-C port requires fast role swap (FRS), the DC/DC converter has to be enabled and kept on standby all the time, even if an adapter is plugged into the USB Type-C port. When the adapter is disconnected, the back-to-back MOSFETs in the discharging power path turn on, passing the U3 output voltage to VBUS and holding on the VBUS voltage. Keeping the DC/DC converter always on actually causes extra quiescent current loss for the entire system.

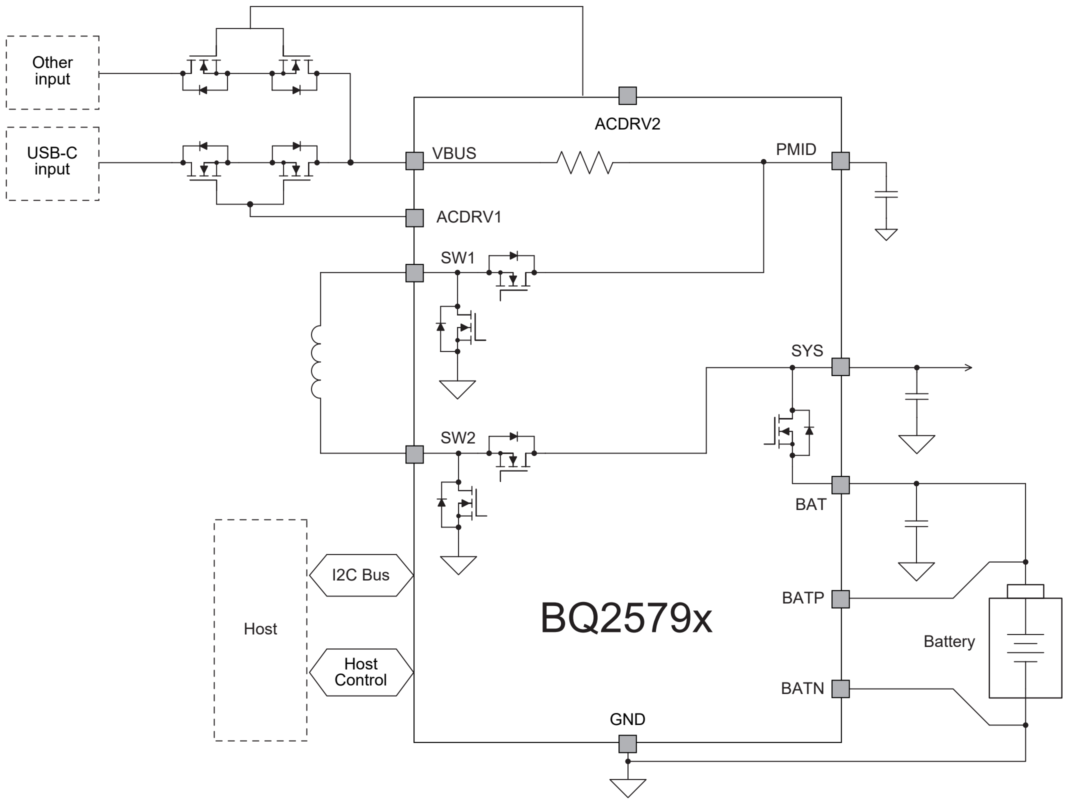

Figure 2. Example of a fully integrated buck-boost charger.

Integrated components maximize power density

As described so far, the USB PD charging solution involves multiple external devices, including control units, MOSFETs and sensing resistors, which have not been optimized in terms of solution size and BOM cost.

The fully integrated buck-boost charger shown in **Figure 2** can simplify the system-level design of a USB PD charging solution. First, the input current sensing is integrated into the charge. With this sensed input current, the charger provides the input current regulation and input overcurrent protection to avoid adapter overload. As part of the input overvoltage and overcurrent protection circuit, the control logic and driving circuitry for the external back-to-back MOSFETs are also integrated into the charger. These features make it possible to eliminate the unit that supports input power-path management and input current sensing from the block diagram.

Multiple input sources are a common trend in portable devices. For example, the input source could be a USB adapter, conventional barrel-jack adapter, charging case or solar power. The two drivers for the back-to-back MOSFETs enable the charger to select the input voltage from two different input sources.

The charger also integrates all four switching MOSFETs, the related control logic and the drivers. The battery FET to manage the NVDC power path is integrated inside the charger. By sensing the charging current flowing through the battery FET, you can eliminate the external sensing resistor at the charger's output side.

Implementing the bidirectional operation of the four FETs' buck-boost converter allows the charger to support OTG mode itself. When the adapter is present, the charger operates in forward charging mode with power flow from VBUS to the battery.

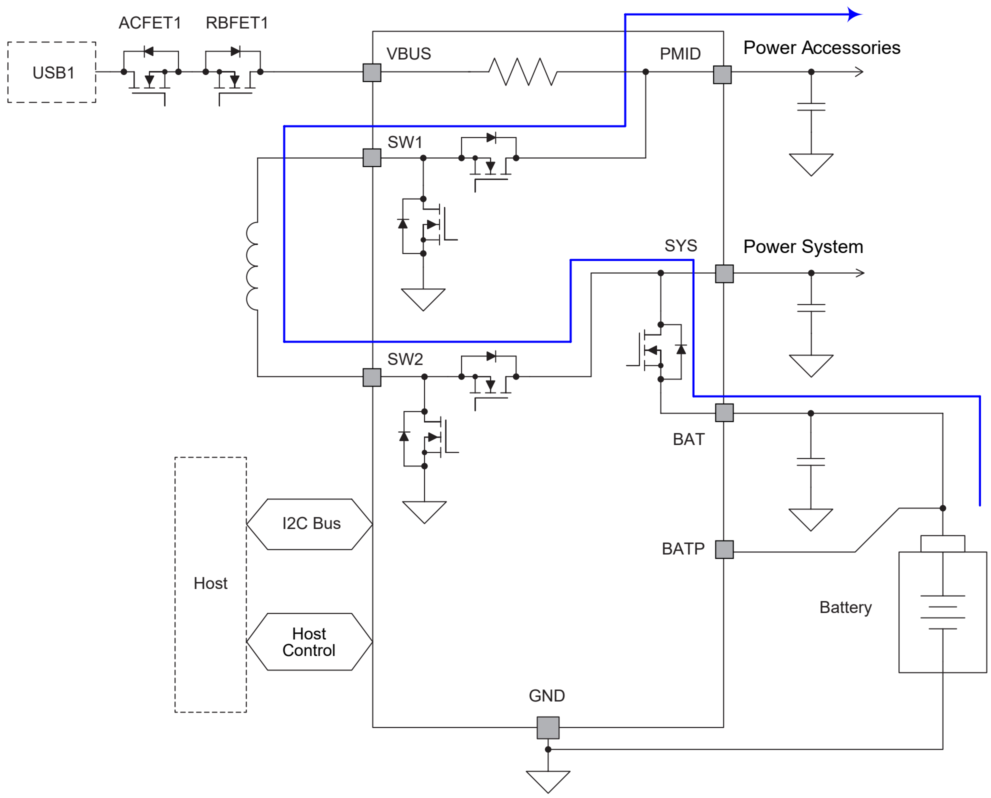

***Figure 3.** USB Type-C™ FRS realized by single buck-boost charger.*

When the adapter is disconnected, the power flow reverses from the battery to VBUS. The OTG mode output voltage at VBUS covers the full USB PD voltage range, from 2.8 V to 22 V with a 10-mV programmable step size, which is compatible with the USB PD 3.0 specification.

In order to support FRS for the USB Type-C port, this integrated buck-boost charger implements a novel backup mode. In this context, backup mode refers to an ultra-fast transition for the buck-boost charger from forward charging mode to reverse OTG mode without the bus voltage crashing. Looking at the application diagram in **Figure 3**, the adapter connects at the USB port, powering the system and charging the battery through the buck-boost power stage. At the same time, the adapter could power accessories from the charger's PMID output. When the adapter is disconnected, the battery's internal FET can still power the system; however, the accessories at PMID might lose power.

With backup mode enabled, the charger is able to monitor the VBUS voltage; the VBUS voltage dropping lower than the preset threshold indicates the adapter's removal. Once it detects a removal, the charger shifts from forward charging mode to OTG mode with minimal delay time, discharges the battery to regulate the VBUS voltage, and achieves FRS by itself. When the adapter is unplugged, the sources to power the system and accessories can switch from the adapter to the battery seamlessly, making it possible to eliminate the DC/DC converter for OTG mode and FRS from the block diagram.

Figure 4 shows the tested waveforms of the charger backup mode for FRS. A 9-V adapter is connected at USB1 as the input power. VBUS is shorted to the adapter by turning on ACFET1-RBFET1. Assume that there is a 1-A accessory current at PMID and a 1-A charging current at BAT. When the 9-V adapter voltage (VAC) is gone, the PMID and VBUS can still be regulated at 5 V to continuously power the 1-A PMID load.

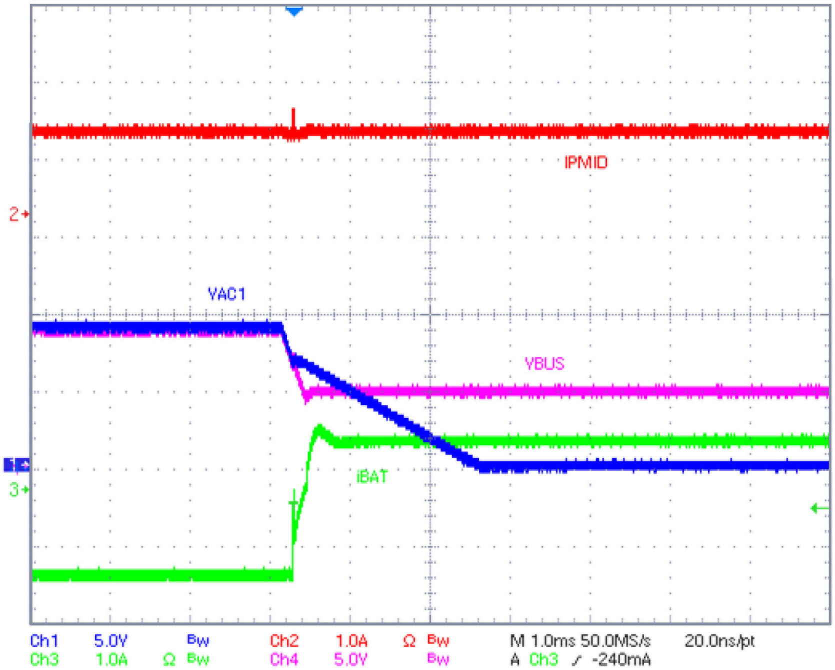

Figure 4. *Buck-boost charger FRS from VBUS sink to VBUS source.*

Implementing buck-boost charging

All of the features described so far, which help simplify the system-level design of a USB PD charging solution, have been implemented in TI's BQ25790 and BQ25792 buck-boost chargers. These devices support one cell in series (1s) to 4s battery charging from a 3.6-V to 24-V input voltage, which covers the full USB PD input voltage range.

The BQ25790 and BQ25792 include:

- A dual-input power multiplexer for input source power-path management and selection.
- USB battery charging 1.2 and high-voltage dedicated charging port adapter detection.
- Input current-sensing, regulation and protection circuits.
- Four switching MOSFETs for the buck-boost converter.
- One battery MOSFET for NVDC power-path management and charging the current sensor.
- A 16-bit analog-to-digital converter for monitoring and optimizing system performance.
- USB Type-C OTG and FRS operations.

These features are available in a 2.9-mm-by-3.3-mm wafer chip-scale package or a 4-mm-by-4-mm quad flat no-lead package. The total charging solution is capable of delivering 45 W of power, with around 100 W/in^2 (150mV/mm^2) of power density, which is two times more than competitive devices.

Summary

Buck-boost chargers benefit small, portable electronics because they deliver a faster charge and come with integrated components to maximize power density, keep the overall design footprint small and reduce BOM. When combined with a USB Type-C PD adapter, buck-boost chargers can deliver quick charging on-the-go for an improved and more convenient user experience.

For more information, review these additional resources:

- BQ25790 data sheet.
- BQ25790EVM user guide.
- BQ25792 data sheet.

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