Understanding USB-C Buck-Boost Battery Charging

Abstract

This white paper analyzes the evolution of power delivery architectures driven by the adoption of USB Type-C®, which enables bidirectional power and data transfer through a single interface. It highlights the challenges of charging batteries across wide input and output voltage ranges and compares conventional approaches such as pre-boost and buck/boost configurations. The paper concludes that the buck-boost charging topology offers superior flexibility, efficiency, and compactness, making it an optimal solution for next-generation USB-C powered systems.

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Introduction

With the widespread adoption of USB Type-C® and USB Power Delivery (USB PD) technologies, standardized by the USB Implementers Forum[1], modern computing platforms—including notebooks, tablets, 2-in-1 systems, and peripheral devices—are increasingly converging on a unified USB-C power interface.

This transition introduces new requirements for system power architectures, including support for bidirectional power flow, higher power levels enabled by USB PD Extended Power Range (EPR), and dynamic power role management. As a result, system designers must rethink traditional power delivery implementations to accommodate these evolving standards.

This article reviews conventional PC power architectures and examines how they are evolving with the adoption of USB Type-C® connectors and advanced USB PD capabilities. It also explores various battery charging topologies and highlights how a USB-C buck-boost charging architecture provides the flexibility, high efficiency, and compact solution size required for modern portable system designs.

Legacy Power Supply for Computing

While charging electronic devices through USB-A/B ports has historically been widely used for low-power applications such as smartphones and tablets, these legacy interfaces are limited in both voltage and current capability. Traditional USB-A/B ports typically provide a fixed 5V supply with limited current, making them unsuitable for higher-power devices.

In contrast, USB Type-C® combined with USB Power Delivery(USB PD)has become the standard interface for modern power delivery across a wide range of electronic devices, including notebooks, tablets, smartphones, and peripheral systems. USB-C enables scalable voltage and current levels through dynamic negotiation between connected devices. With the introduction of USB PD Extended Power Range(EPR), power delivery capability has increased significantly, reaching up to 240W, enabling USB-C to support even high-performance computing platforms that traditionally relied on dedicated AC adapters.

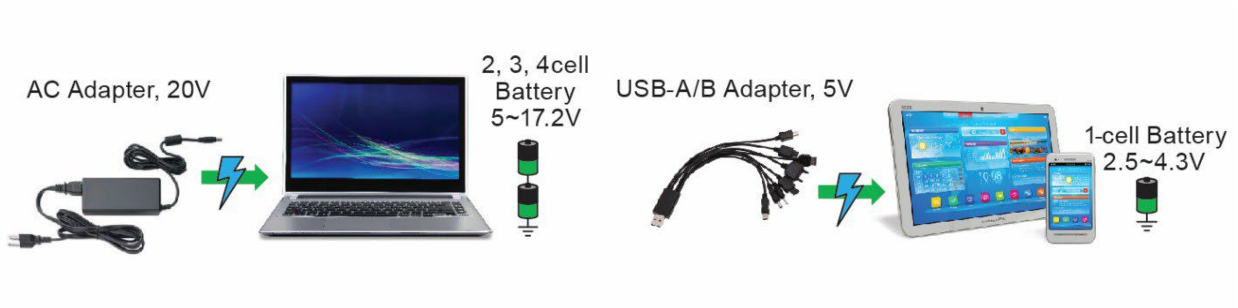

Figure 1. *Lagacy Power Supply architecture*

A conventional computing power architecture typically includes an AC adapter that converts AC voltage to a fixed DC output, often around 19V to 20V, to power and charge the main electronic device, such as a notebook computer. These systems may utilize battery stacks ranging from 1-cell to 4-cell Li-ion batteries, where each cell typically operates between approximately 2.5V and 4.3V depending on its state of charge. As a result, the total battery voltage can range from approximately 2.5V to 17.2V.

In such systems, the battery charger commonly employs a buck topology to step down the adapter voltage to charge the battery. For legacy USB-A ports, the system generates a regulated 5V rail to power external devices such as smartphones or tablets. This 5V rail is typically derived from the system battery or adapter using a buck converter, or a boost converter in single-cell battery systems.

The Transition to USB Type-C®

USB Type-C® is fundamentally transforming how power is delivered and managed in electronic systems. It provides a universal, reversible connector that supports both high-speed data and bidirectional power delivery. Unlike legacy interfaces, USB-C enables dynamic power negotiation, allowing devices to operate as either power sources or sinks depending on system requirements.

Through USB Power Delivery, USB-C ports can negotiate voltage and current levels dynamically, supporting a wide range of operating points. In addition to the Standard Power Range (SPR, up to 100W), the Extended Power Range (EPR) further increases available power, enabling support for high-performance devices such as notebooks, gaming systems, and docking solutions.

***Figure 2**. Modern power delivery architecture based on USB Type-C®*

With the adoption of USB-C charging, traditional power architectures are evolving significantly. A USB-C port can now accept input power across a wide voltage range (for example, 5V to 28V in EPR systems) and efficiently charge devices with various battery configurations, including 1- to 4-cell battery stacks.

In modern systems, USB-C ports not only receive power but can also supply power to external devices, such as smartphones, tablets, and other peripherals. This bi-directional capability enables flexible system designs, including power sharing and multi-port configurations.

As a result, power management systems must now support wider input voltage ranges, bidirectional power flow, dynamic power negotiation, and higher efficiency across diverse operating conditions. Advanced buck-boost charging architectures have therefore become essential to meet these requirements, providing the flexibility, efficiency, and compact system design needed for today’s computing platforms.

Different USB-C Battery Charging Approaches

A key challenge in modern USB Type-C® power delivery architectures is efficiently converting a wide input voltage range (typically 5V to 28V with USB Power Delivery Extended Power Range, EPR) to the battery voltage range (approximately 2.5V to 17.2V for 1- to 4-cell Li-ion batteries). Because the relationship between the input voltage and the battery voltage varies dynamically depending on operating conditions, neither a pure buck nor a pure boost topology alone can provide an optimal solution across all scenarios.

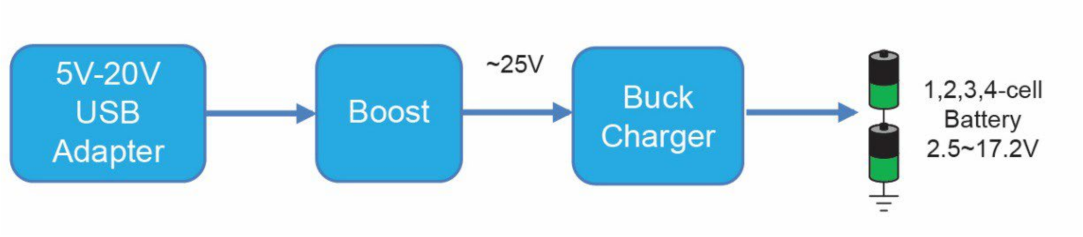

Figure 3. *The pre-boost approach*

Figure 3 illustrates an approach based on the pre-boost concept. In this configuration, the USB-C adapter voltage is first boosted to a level higher than the maximum input voltage (for example, around 25V or higher), and then a downstream buck charger is used to regulate the battery charging voltage. While this approach ensures that the charger always operates in a step-down mode, it requires an additional boost converter stage. This increases system cost, solution size, and reduces overall efficiency due to additional power loss in the pre-boost stage.

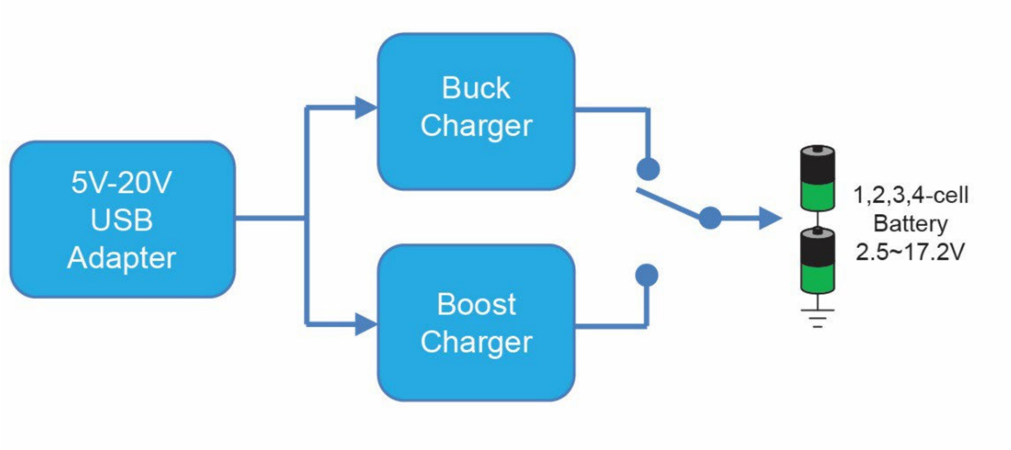

Figure 4. *The buck charger or boost charger approach*

Figure 4 shows an alternative approach using either a buck charger or a boost charger, depending on the relationship between the input voltage and the battery voltage. This method eliminates the dedicated pre-boost stage and improves efficiency compared to the previous approach. However, it still requires multiple power conversion paths or additional circuitry to support both step-down and step-up conditions, which increases system complexity, solution size, and cost.

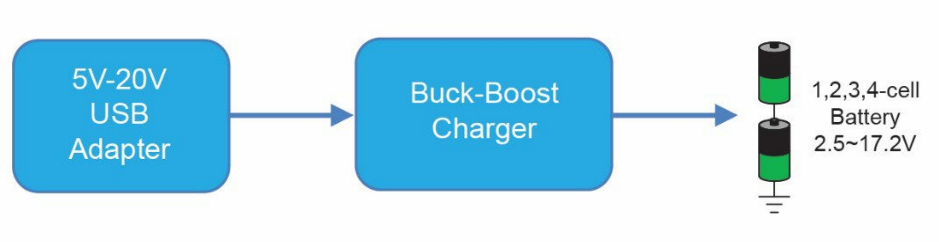

Figure 5. *The buck-boost charger approach*

A buck-boost topology, shown in Figure 5, provides a more integrated and efficient solution. It seamlessly operates in buck mode when the input voltage is higher than the battery voltage, in boost mode when the input voltage is lower, and in buck-boost mode when the two are comparable.

This flexibility enables a single-stage power solution that minimizes component count, reduces system size, and improves overall efficiency across the full operating range. As a result, the buck-boost charger architecture meets the key requirements of modern USB-C power systems, including wide input voltage support, bidirectional operation capability, and optimized performance under all operating conditions.

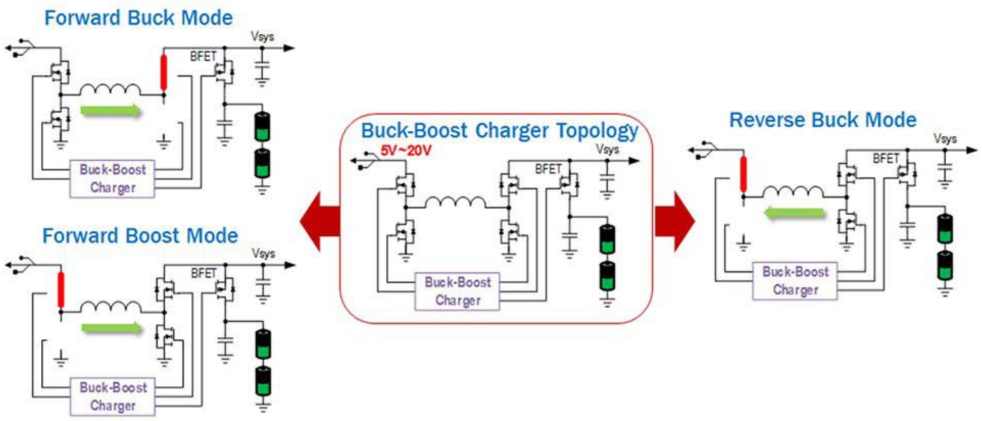

Figure 6. *A buck-boost charger topology*

A modern USB Type-C® buck-boost battery charging solution is represented by the Renesas RAA489110[2]. Figure 6 illustrates the topology of a typical buck-boost charger based on this architecture. The RAA489110 employs a four-switch buck-boost topology consisting of four switching MOSFETs, a single inductor, and a battery connecting FET (BFET). The switching stage is organized into a buck leg and a boost leg, enabling seamless operation across different power conversion modes. This architecture allows the device to operate in buck mode when the input voltage is higher than the battery voltage, in boost mode when the input voltage is lower, and in buck-boost mode when the input and battery voltages are comparable. In addition, the device supports reverse operation, enabling power delivery from the battery to the USB Type-C® port to support external devices such as smartphones, tablets, and portable power systems.

The RAA489110 provides an advanced feature set and supports SMBus/I²C communication with a system host or embedded controller. It is designed to meet modern platform requirements, including USB Type-C® Power Delivery with support for Programmable Power Supply (PPS) and Extended Power Range (EPR), as well as Intel IMVP-compliant features such as PROCHOT# and system power monitoring (PSYS). The device integrates multiple protection and monitoring functions, including adapter overcurrent, battery overcurrent, thermal protection, and system voltage regulation. It also supports programmable multi-level adapter current limits to optimize the use of adapter power capability. In addition, the RAA489110 supports a wide range of input sources, including standard AC/DC adapters, USB PD sources, travel adapters, and power banks. Its flexible architecture enables robust operation even when the input power capability is variable or dynamically negotiated.

Conclusion

With the introduction of advanced USB Type-C® buck-boost battery chargers such as the Renesas RAA489110, modern mobile PC systems and portable devices can achieve highly efficient two-way power delivery using the reversible USB Type-C® connector. USB Type-C® simplifies power and data connectivity by supporting bidirectional power flow and dynamic power negotiation through USB PD. With the addition of Extended Power Range (EPR), USB-C now enables significantly higher power levels suitable for a wide range of computing platforms. his evolution of the USB-C ecosystem enables a unified power interface, where a single cable can support diverse devices and applications, simplifying system design while improving user experience.

References

[1] USB Implementers Forum www.usb.org

[2] Renesas RAA489110 https://www.renesas.com/en/products/RAA489110

Revision History

Revision	Date	Description
2.00	Jun 18, 2026	USB spec related information and product information updates
1.00	Aug 2018	Initial release.

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