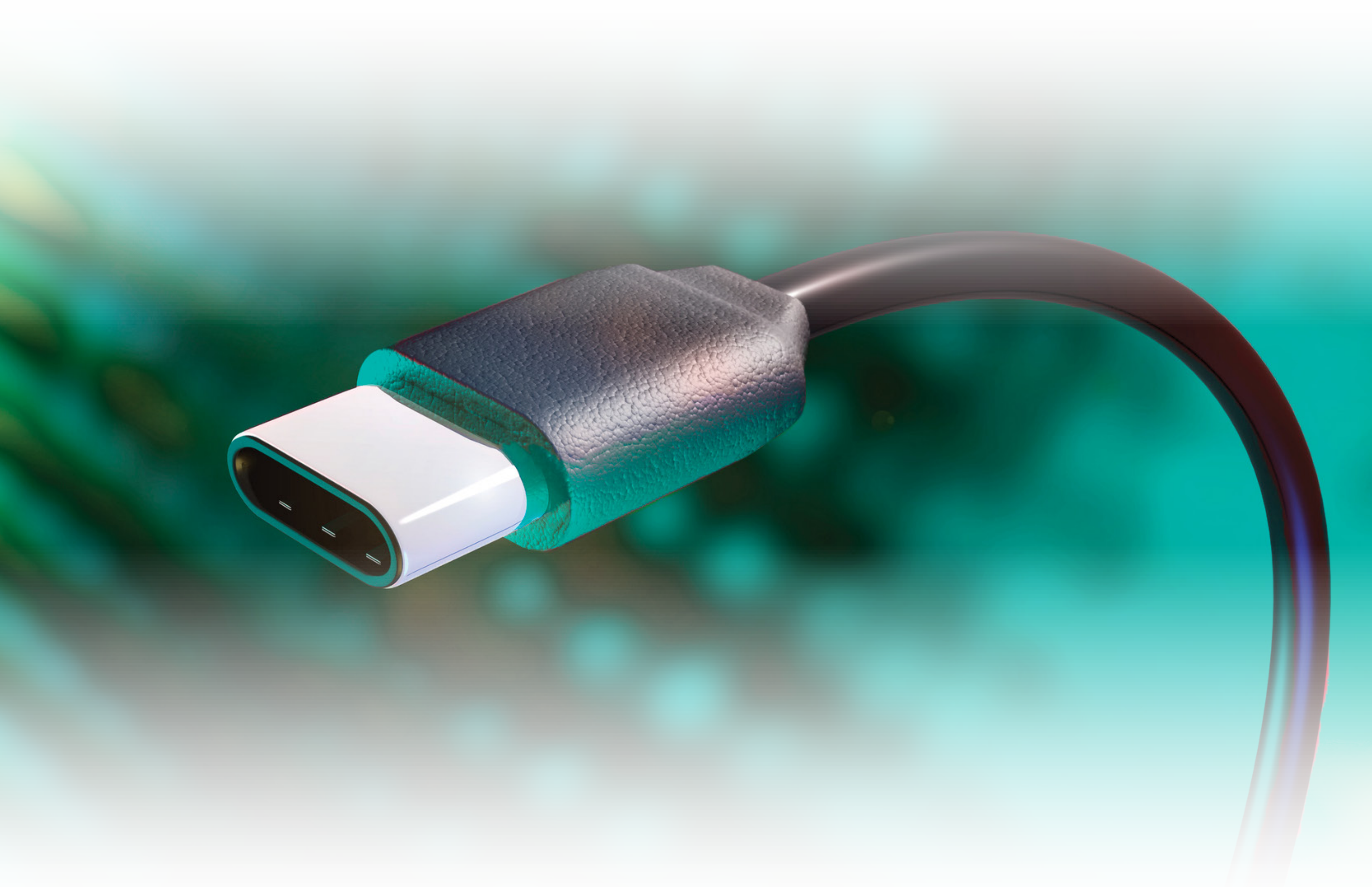
USB-C AND USB POWER DELIVERY SOLUTIONS

Design Guide



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Introduction

Every electronic market is rapidly adopting the latest USB Type-C® and USB Power Delivery (USB-PD) specifications. The new USB Type-C cable and connector specification dramatically simplifies the way we interconnect and power our electronic gadgets such as smartphones and ultra-thin portable computers. With the proliferation of battery-operated devices for consumer (***Figure 1***), medical, automotive, and industrial applications, USB-C is increasingly becoming the preferred universal standard for charging and powering of devices. The USB-C specification supports charging applications up to 15W, while USB-C power delivery (PD) extends charging up to 100W to include a wide variety of devices. Accordingly, more functionality is required from the power management system, which tends to be smaller and lighter for every new portable device. This design guide reviews the USB Type-C architecture and its associated technological challenges. It then examines new solutions to address these challenges in the area of power management, protection, and voltage regulation through several examples.

Figure 1. USB-C Cable in the Consumer Space

USB-C Cables

USB-C supports high data rates and increased power delivery between electronic products. It can deliver 10Gbps of throughput while delivering up to 3A with 5V (15W) over standard cables and a basic Configuration Channel (CC) detection. The USB-C PD specification extends operation up to 5A and 20V. With PD, the bus power can be set up to 60W at 3A with a standard cable or 100W at 5A with an electronically marked or active cable. These power levels satisfy the requirement of most portable electronics, hence new models are increasingly adopting a Type-C connector for charging.

While USB-C adds simplicity and convenience for the end user, it also adds complexity to the design. USB-C specification requires a device to negotiate to be either a power provider (source) or power user (sink) before power transfer takes place. The connectors at both ends of a Type-C cable are identical, allowing for reversible plug-in. Each connector is also flippable, which allows it to be plugged in without worrying about polarity. USB-C also allows for bidirectional power; hence a peripheral device can be charged, and the same device can also supply power to a host device. This eliminates many proprietary power adapters and many types of USB cables, ultimately reducing the maze of wires surrounding today's devices.

Configuration Channel (CC) Detection

The configuration channel logic detects cable presence, orientation, as well as power role and current-carrying capability. CC detection is new compared to the legacy USB in which 5V is available without any detection. Cable detection occurs when one of the two CC lines is pulled up or pulled down. A device configured as a sink has the CC lines pulled down whereas a device configured as a source has the CC lines pulled up. The voltage level detected on the CC1 and CC2 lines determines the cable orientation as well as the source current capability. Another feature of USB-C is cold-plugging, namely the V_{BUS} voltage is provided only after successful end-to-end detection is completed. This feature makes CC detection mandatory in USB-C applications.

Standard USB-C System (Up to 15W)

Figure 2 illustrates a typical portable power management front-end equipped to connect to a USB-C cable and powered by a Li+ battery. The system's various blocks include USB-C CC detection, legacy USB Battery Charging 1.2 (BC1.2) detection, the power conversion block and protection block. Each of these blocks can be implemented as separate ICs or with ICs combining two or more functions.

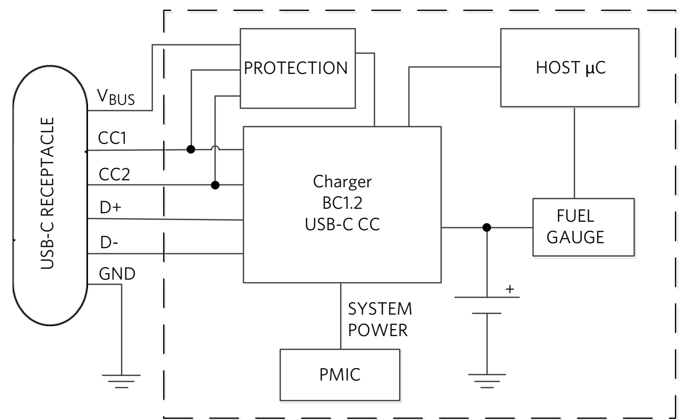

Figure 2. USB-C Power Management System

When the V_{BUS} is present it powers the charger, the system, and the rest of the blocks. In this state, the battery is charged. When the V_{BUS} is disconnected, the battery powers the system and other blocks.

USB PD System

Figure 3 shows the USB PD system. Here a PD controller implements the USB-C PD protocol.

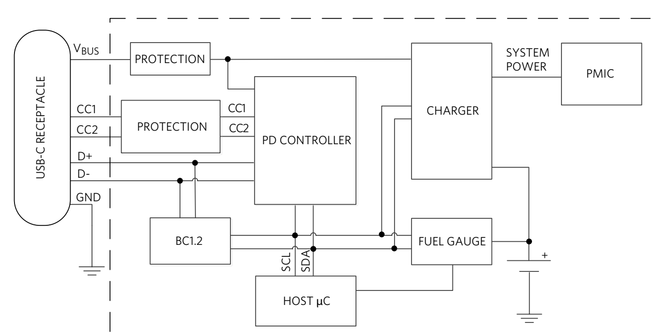

Figure 3. USB PD Power Management System

PD Controller (Up to 100W)

The PD controller is an extension of the CC detection. In addition to performing the standard CC detection functions, the PD controller also advertises power capabilities and negotiates a power contract with the device on the other side of the cable. This power contract may consist of voltages from 5V to 20V and currents up to 5A. The PD controller can also perform power and data role-swapping as a subsequent step following the initial connection process.

Challenges

The adoption of USB-C connectivity by a wide variety of portable devices places new requirements on system hardware including: achieving USB-C and USB-C PD compliance, constraints on component size to fit additional electronics in the same space, support for higher power levels with the same or lower thermal budget, and increased electrical/mechanical safety and reliability to reduce failures.

Applications

USB-C is found in smartphones, tablets, laptops, point-of-sale terminals, digital cameras, handheld computers, portable printers, and other portable medical, industrial, and automotive equipment. Depending on the power level required, the system may be implemented with standard USB-C or with USB-C PD. In either implementation, the system may be designed with a single-cell (1S) Li+ battery or multiple series cells (2S, 3S, etc.). In the next sections, we will discuss the solutions to the challenges posed by each implementation.

Single-Cell Charger with USB-C

For single-cell applications, a high level of integration (see Figure 2) is obtained with the **MAX77860**, a high-performance, single-input switch-mode charger (*Figure 4*), which features USB-C CC, BC1.2, DCP, and CDP detection capability for single-cell Li+ batteries. The IC supports up to 15W applications and includes reverse-boost capability, an always-on LDO, and a 6-channel ADC. The switching charger is designed with a robust constant current, constant voltage (CC-CV), die temperature regulation algorithm, and input power regulation, as well as I²C programmable settings to accommodate a wide range of battery sizes and system loads. It is available in a compact 3.9mm x 4.0mm WLP package.

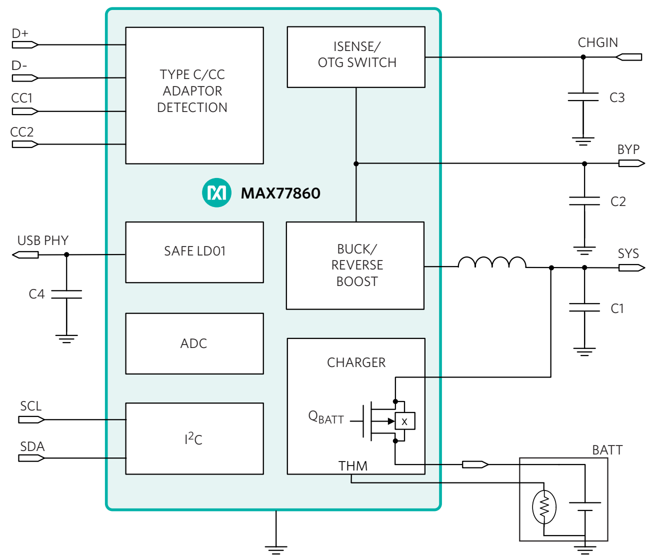

Figure 4. Integrated Charger PMIC

The corresponding PCB layout is shown in *Figure 5*. The integrated solution plus passives occupies only 42mm², a 30% reduction in PCB size compared to competitor solutions.

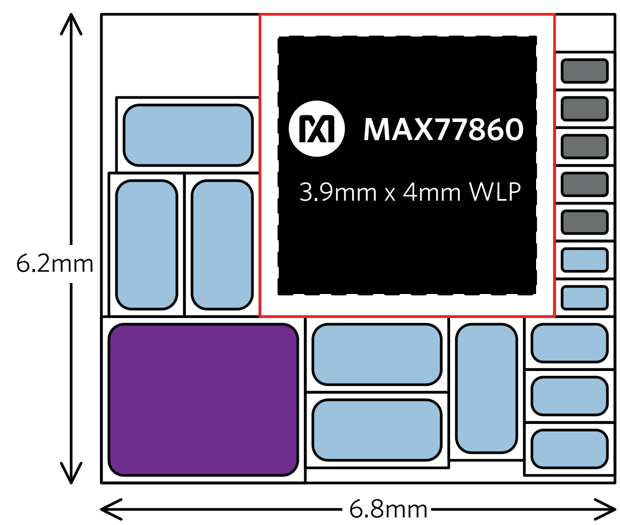

Figure 5. Highly Integrated Solution with Small PCB Size (42mm²)

Ease of Use

In a typical system, the microcontroller or a host microprocessor configures the charger's input current limit based on the current level that the port controller IC detects. The MAX77860 independently performs USB-C CC detection and sets the charger's input current limit, allowing the charger to charge the battery at the source's full capability. This also simplifies host software development.

The MAX77860 also supports legacy adapters with built-in USB BC1.2 detection.

A similar device is the **MAX77751**. The IC integrates CC detection and BC1.2 detection and is configured only with two resistors. As a result, it enables USB-C charging while eliminating the need for any software development. It is available in a small 3mm x 3mm, 24-lead FC2QFN package

Two-Cell Charger with USB-C

The **MAX14748** is an ideal solution for standard USB-C charging of two-cell (2S) Li+ batteries. It integrates USB-C CC detection, BC1.2 detection, and a boost charger with smart power selector to provide fast and safe charging of 2s Li+ battery packs.

Two-Cell and Three-Cell Chargers with PD Control

Applications such as digital cameras, AR/VR devices, and handheld computers are loaded with features. These devices utilize two-cell or three-cell (2S, 3S) Li+ batteries and require USB-C PD for fast charging. Referring to Figure 3, in addition to the charger, we need a PD controller and a protection IC for the CC lines.

2S or 3S batteries exhibit large voltage swings: between 6.5V and 8.4V for 2S, and 8V and 13.2V for 3S. On the other hand, some adapters may only be capable of sourcing 5V, while others may support higher voltages up to 20V for faster charging. With an adapter voltage that may be above or below the battery voltage, charging a 2S or 3S battery requires a buck-boost converter.

Buck-Boost Chargers (2S and 3S)

As an example of a 2S charger, the **MAX77962** (*Figure 6*) is a high-performance wide-input 3.2A buck-boost charger with a Smart Power Selector™. It also operates as a reverse buck without an additional inductor, allowing the IC to power USB On-the-Go (OTG) accessories. The device integrates low-loss power switches, and provides small solution size, high efficiency, low heat, and fast battery charging. The reverse buck has true-load disconnect and is protected by an adjustable output current limit. The device is highly flexible and programmable through I2C configuration or autonomously through resistor configuration. It enables safe charging with a thermistor monitor and JEITA-compliant charging. For 2S operation, the battery regulation voltage ranges from 8.10V to 8.86V. The IC is available in a 3.5mm x 3.5mm, 49-bump WLP package.

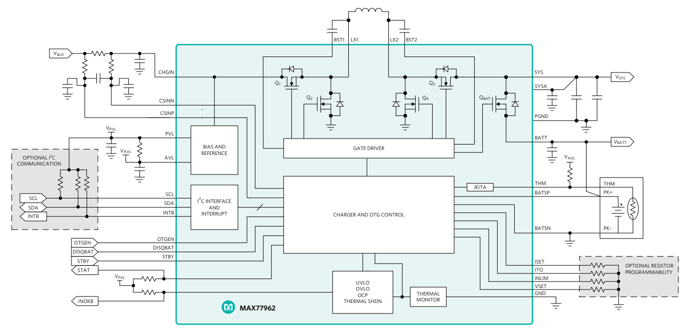

Figure 6. Buck-Boost 2S Charger

PD Controller Example

The **MAX77958** (*Figure 7*) is a robust solution for USB-C CC detection and PD protocol implementation. It offers out-of-the-box compliance to the USB-C and PD 3.0 specification. It detects connected accessories or devices by using Type-C CC detection and USB PD messaging. The IC protects against overvoltage, overcurrent, and shorts to V_{BUS} and GND. It detects moisture and prevents corrosion on the USB Type-C connector. The IC also has a D+/D- USB switch and BC1.2 detection to support legacy USB standards. It contains VCONN switches for USB PD and an enable pin for an external VCONN boost or buck converter.

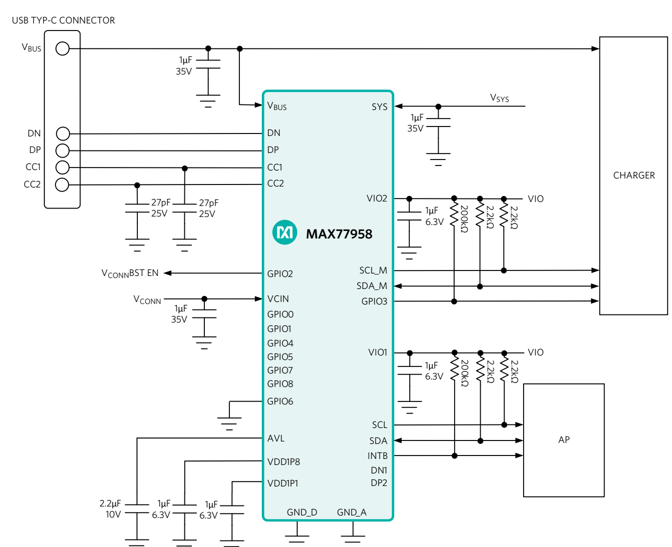

Figure 7. PD Controller

The IC has an I2C master that can read and write to other devices in the system autonomously without assistance from the application processor. The interrupt output pin can report USB-C PD events and status changes. For systems controlled by an application processor, the MAX77958 is equipped with a slave I2C interface through which the system can read/write and configure internal registers. The IC has nine configurable GPIOs that can be used for detection, as interrupts, as the enable/disable pin for external devices, or as ADC inputs. The IC is available in a 3.10mm x 2.65mm, 0.5mm pitch, WLP package.

Automotive Dual USB-C Power Source

USB ports are pervasive in automobiles. The electronic modules that implement these functions must fit inside small spaces without overheating. The problem is exacerbated in the case of dual-port USB-C dedicated charging solutions (*Figure 8*), which must support two connectors with higher power without increasing component count and solution size.

Figure 8. Dual USB-C Ports in a Modern Car

Figure 9 illustrates a dual USB Type-C high-power delivery system. With a car battery, which is normally at 14V under charge and dips to a minimum of 6V during start/stop, PD output voltages can vary from 5V to 20V. The only possible choice for a voltage regulator to provide an output voltage V_{BUS} is through the use of a buck-boost converter (see orange color blocks). The charge emulation and protection IC takes the PD controller signals and passes them along to the USB Type-C connector.

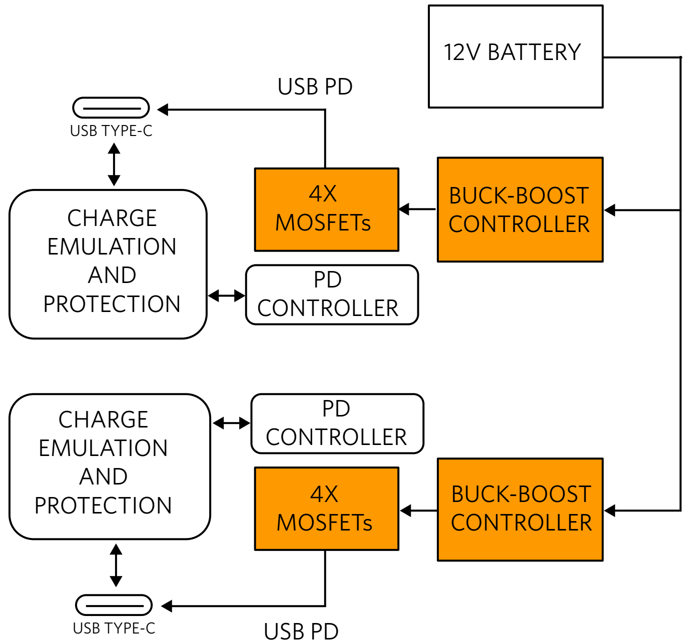

Figure 9. Buck-Boost Power Delivery and Protection Architecture

The **MAX25431** is a current-mode buck-boost controller (*Figure 10*). The device operates with input voltages from 6V to 36V. The switching frequency is resistor-programmable from 220kHz to 2.2MHz and can be synchronized to an external clock. The wide input voltage range, along with its ability to maintain constant output voltage during battery transients, makes the device ideal for automotive applications. An external frequency applied to the logic input (FSYNC) allows the devices to operate in a fixed-frequency, forced-PWM mode to eliminate frequency variation and help minimize EMI. Protection features include cycle-by-cycle current limit followed by hiccup during sustained overloads, input undervoltage lockout (UVLO), output overvoltage protection, and thermal shutdown with automatic recovery. The MAX25431 is available in a small 4mm x 4mm, 24-pin TQFN-EP SW package.

This highly integrated buck-boost controller IC, in conjunction with low $R_{DS(ON)}$ external MOSFETs, yields high efficiency, keeping the temperature rise within the allowed limit.

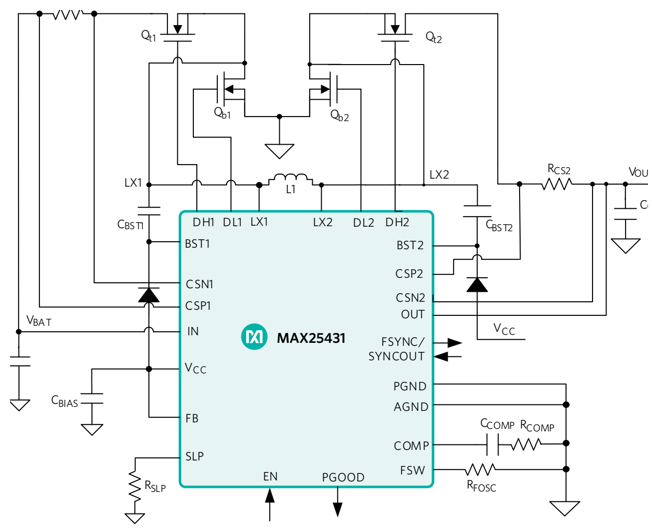

Figure 10. Buck-Boost Application Diagram

USB Type-C CC-Pin Overvoltage Protector

With USB Type-C comes new challenges in protecting the system. The new connector has a smaller pitch than that of the USB Micro-B, leading to increased risk of mechanical shorts to V_{BUS}. Additionally, due to the high voltages associated with USB PD, more robust protections are needed.

The **MAX20323** family of overvoltage protectors feature internal overvoltage threshold and surge protection to turn off the switches and prevent damage to USB-C CC/SBU pins. *Figure 11* shows three of seven members of the family.

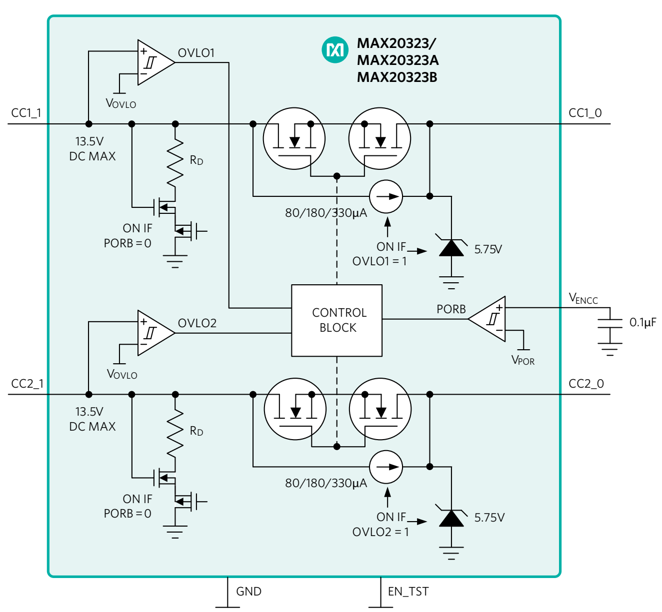

Figure 11. USB Type-C CC-Pin Overvoltage Protector

The devices have two-channel switches with 0.27Ω (typ) on-resistance that are turned on when inputs are below overvoltage threshold. When overvoltage threshold is exceeded on one of the channels, the corresponding switch is turned off and replaced by an accurate pullup current to output (CC1_O/CC2_O) that is sourced from input (CC1_I/CC2_I). The MAX20323A/F do not have the pullup current feature. The devices are available in a 12-bump (0.4mm pitch, 1.7mm x 1.32mm) WLP package.

PMICs

The system power pin (for example V_{SYS} in Figure 6) powers various rails from the battery or from the V_{BUS} when available. A few cases of powering the device rails are shown in the following section.

Always-On Rail

The always-on buck converter plays a key role in portables. During normal operation, the power source has the ability to change capabilities at any time, forcing the sinking device to renegotiate, hence the necessity for the buck converter to be always 'on'. Accordingly, the always-on buck converter should be selected to consume minimum power.

As an example, the **MAX77596** (*Figure 12*) is a small, synchronous buck converter with integrated switches (T1 and T2 in Figure 12). For an always-on device, low quiescent current is critical since the device is never shut down. The MAX77596 fixed output version allows most of the internal circuitry to be biased from the V_{OUT} pin (I_{BIAS}). Accordingly, the associated power losses are minimized.

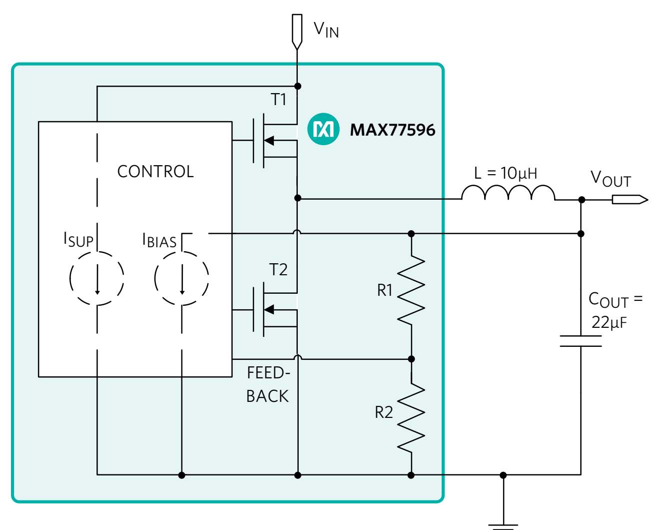

Figure 12. MAX77596 Buck Converter Fixed Output

The device is designed to deliver up to 300mA with input voltages from 3.5V to 24V, while using only 1.1µA quiescent current at no load (fixed-output version). It can operate near dropout by running at 98% duty cycle, making it ideal for battery-powered applications.

The MAX77596 is available in a small (2mm x 2.5mm) 10-pin TDFN package.

Back-Up Power Rail

Figure 13 illustrates an example in which the USB PD provides the main power while the backup power is a battery or a solar cell array. In this case, an input multiplexer is necessary to provide always-on power to the load.

The **MAX77756** is a synchronous 500mA step-down DC-DC converter with integrated dual-input power multiplexer (MUX). The converter operates on an input supply as low as 3.0V and as high as 24V. The default output voltage is factory-programmed to either 1.8V, 3.3V, or 5.0V. Output voltage is further adjustable through external resistors or an I²C serial interface.

Summary

USB Type-C simplifies the way we interconnect battery-operated power devices. USB-C and USB-C PD implementations create challenges including achieving USB compliance, thermal management for high power, smaller solution sizes, and a need for greater safety and reliability.

- For powering applications below 15W, we proposed chargers with integrated USB-C detection, namely the MAX77860 and MAX77751 for 1S and the MAX14748 for 2S Li+ batteries.
- For higher power and multiple cell solutions (2S, 3A), we proposed the MAX77962 buck-boost charger in conjunction with the MAX77958 PD controller.
- For added overvoltage and surge protection on the CC and SBU pins, we proposed the MAX20323.
- For dual USB-C automotive power sourcing, we discussed the MAX25431.
- And finally, for regulation, we proposed the MAX77596 for standby and the MAX77756 for backup power applications.

Thanks to a high level of integration, advanced packaging and flexible architectures, our USB-C portfolio, including charger, power management and protection solutions, overcome the critical challenges faced by today's USB-C implementations.

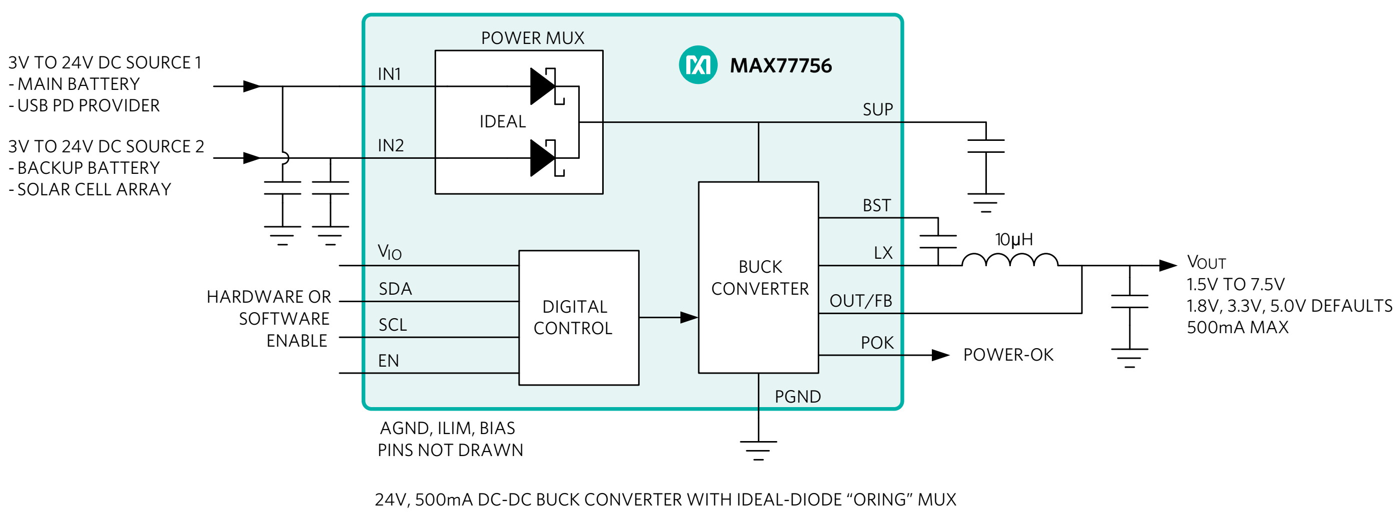

Figure 13. MAX77756 Buck Regulator with Dual-Input Power MUX

Product Selector Table

Table 1 highlights the product portfolio for USB-C, USB-C Power Delivery, Protections, and PMIC solutions.

Table 1. USB-C and USB C Power Delivery Solutions

Part	Functionality	Description
USB-C PD Controllers		
MAX77958	PD Controller	USB Power Delivery Controller
USB-C Chargers		
MAX77976	1-Cell Buck Charger	$19V_{IN}$, $5.5A_{OUT}$ I^2C Configured 1-Cell Buck Charger with Integrated FETs for USB Power Delivery
MAX77975	1-Cell Buck Charger	$19V_{IN}$, $3.5A_{OUT}$ I^2C Configured 1-Cell Buck Charger with Integrated FETs for USB Power Delivery
MAX77962	2-Cell Buck-Boost Charger	$25V_{IN}$, $3A_{OUT}$ 2-3 Cell Buck-Boost Charger with Integrated FETs for USB Power Delivery
MAX77961	2-3 Cell Buck-Boost Charger	$25V_{IN}$, $6A_{OUT}$ 2-3 Cell Buck-Boost Charger with Integrated FETs for USB Power Delivery
MAX77960	2-3 Cell Buck-Boost Charger	$25V_{IN}$, $3A_{OUT}$ 2-3 Cell Buck-Boost Charger with Integrated FETs for USB Power Delivery
MAX77860	1-Cell Buck Charger with Integrated USB Type-C	$14V_{IN}$, $3.15A_{OUT}$ I^2C Configured 1-Cell Buck Charger with Integrated FETs and USB Type-C Detection
MAX77757	Autonomous Charger with JEITA	3.15A USB Type-C Autonomous Charger with JEITA for 1-Cell Li-ion/LiFePO4 Batteries
MAX77751	1-Cell Buck Charger with Integrated USB Type-C	$14V_{IN}$, $3.15A_{OUT}$ Resistor Configured 1-Cell Buck Charger with Integrated FETs and USB Type-C Detection
MAX14748	Charger and CC Control with I^2C Configuration	1.5A USB-C Boost Charger with I^2C for 2S Li+ Batteries
USB-C Power		
MAX77756	Buck Converter	500mA, Dual-Input Power Multiplexer (MUX), Input Supply 3.0V to 24V
MAX77596	Buck Converter	300mA, Input Supply 3.5V to 24V, 1.1µA Quiescent Current at No Load

Product Selector Table

Table 1 highlights the product portfolio for USB-C, USB-C Power Delivery, Protections, and PMIC solutions.

Table 1. USB-C and USB C Power Delivery Solutions (Continued)

Part	Functionality	Description
USB-C Power Path and Protection		
MAX14727	Protection	Dual-Input, Bidirectional Overvoltage Protector with Automatic Path Control
MAX20323	Protection	USB Type-C CC-Pin Overvoltage Protector
MAX20328	Protection	MUX Switch for USB Type-C Audio Adapter Accessories
MAX20333	Protection	Adjustable Current-Limit Switch with Low-Power Mode
MAX20334	Protection	Overvoltage and Surge-Protected Dual SPDT Data Line Switch

Related Resources

USB-C Solutions

Reference Designs

MAXREFDES179 Reference Design Board

Design Solutions

How to Shrink Your USB Type-C Battery Charger

Choose the Right Buck Converter for Your USB 3.1 Type C Powered Devices

Application Notes

Simplifying Mobile USB-C Designs

Blogs

Designing for USB-C Just Got Easier

Videos

How to Charge Your Battery with USB Type-C and BC1.2 Ports Using the MAX77860

USB-C Fundamentals

USB Type-C Charging Overview

Trademarks

USB Type-C is a registered trademark of the USB Implementers Forum, Inc. and Smart Power Selector is a trademark of Maxim Integrated Products, Inc.

Learn more

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