24V Universal Serial Bus Type-C (USB-C) Power Supply

MAXREFDES1283

Introduction

Many applications today use a 24V power source whenever size, portability of the equipment and low heat are required in audio, lighting, and sensors applications. This typically involves a heavy 24V AC/DC adapter to plug into the mains. This reference design shows how to achieve the same power supply from a USB C-Type power delivery (PD) source with a small highly efficient DC-DC switching converter. USB-C PD allows communication between compatible devices to negotiate a power contract to determine at what voltage and how much power can be pulled. It can deliver 3A with the supporting voltages between 5V and 20V using a standard USB-C cable, and it is possible to deliver 5A at 20V using a designated Electronically Marked Cable Assembly (EMCA) cable to achieve a maximum power contract of 100W.

This reference design facilitates the PD contract and outputs 24V DC up to 1A to enable applications and products that need a 24V power source to connect to a USB-C PD socket. It utilizes the MAX77958 USB-C PD controller to request 15V from a capable USB-C source, and the MAX668 boost converter to output 24V with an output power capability of up to 30W.

This reference design also includes the MAX17613A circuit protection integrated circuit (IC) that is configured to assert a undervoltage lockout (UVLO) if the input voltage is less than 14V, an overvoltage lockout (OVLO) if the input voltage is greater than 22V and a 2.2A current limiter. The purpose is to make sure that the connected USB source can deliver the required voltage level, to protect the DC-DC converter from sourcing more current than it is designed to handle, and to act as a switch between the USB voltage and the MAX668 so that the MAX668 only turns on once the input voltage has been correctly set.

Other features include the following:

- USB-C PD controller
- Under-voltage and over-voltage lockout
- Over-current limit protection

Applications

- Lighting
- Sensors
- Audio
- Portable equipment

Designed–Built–Tested

This document describes the hardware shown in Figure 1.

Table 1. Design Specification

PARAMETER	SYMBOL	MIN	TYP	MAX
Input Voltage (V)	V_{IN}	14V	20V	22V
Output Voltage (V)	V_{OUT}		24V	
Frequency (kHz)	f_{SW}	180	200	220
Maximum Efficiency	η		90%	96%
Load Current (A)	I_{OUT}		1.0	1.7
V_{OUT} ripple (V)	ΔV_{OUT}		0.8	0.1
Inductor ripple (A)	ΔI_L		0.9	

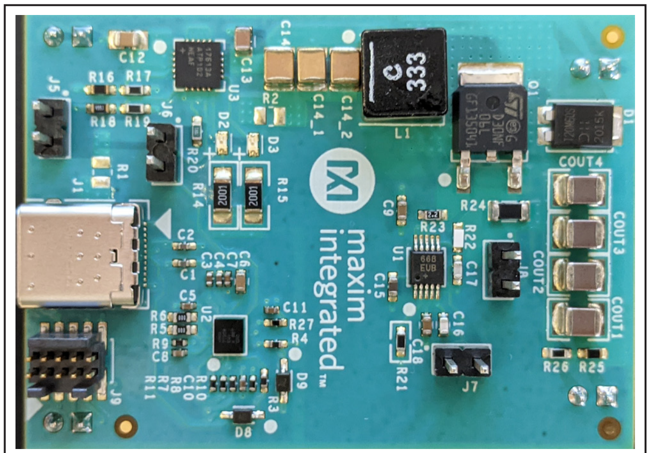

Figure 1. MAXREFDES1283 Hardware.

USB-C is a registered trademark of the USB Implementers Forum, Inc.

Design Procedure

MAX77958 USB-C PD controller

The MAX77958 is a complete solution for USB Type-C CC detection and PD protocol implementation. It can detect connected accessories or devices by using Type-C CC detection and USB PD messaging. It also protects against overvoltage and overcurrent and detects moisture on the USB- Type-C connector. The IC supports USB PD revision 3.0. The purpose of the MAX77958 in this application is to act as a SINK for a USB Type-C power supply capable of providing at least 15V. When a USB Type-C connection is made, the IC automatically handles the initial PD power contract. When a source is connected, it communicates its capabilities. Then, the IC reads and selects an appropriate voltage and current. By default, the IC selects the highest rated power option up to 15V/3A. This reference design works with any USB Type-C supply that can provide at least 15V/3A. The application processor (AP) may later negotiate a new operating power and manually set the input current limit after initial startup.

The Figure 2 shows the connections required to operate in an autonomous mode for a DC-DC application. The VIO voltage is connected directly to AVL to provide a logic level of approximately 2.7V for the internal logic upon startup. There is no need to use a GPIO pin to enable the DC-DC converter as a circuit protection IC is included with UVLO and OVLO, so it only operates when the V_{BUS} voltage is within an appropriate range. This way, the MAX77958 does not need to be programmed, and it is able to perform the PD contract with factory settings.

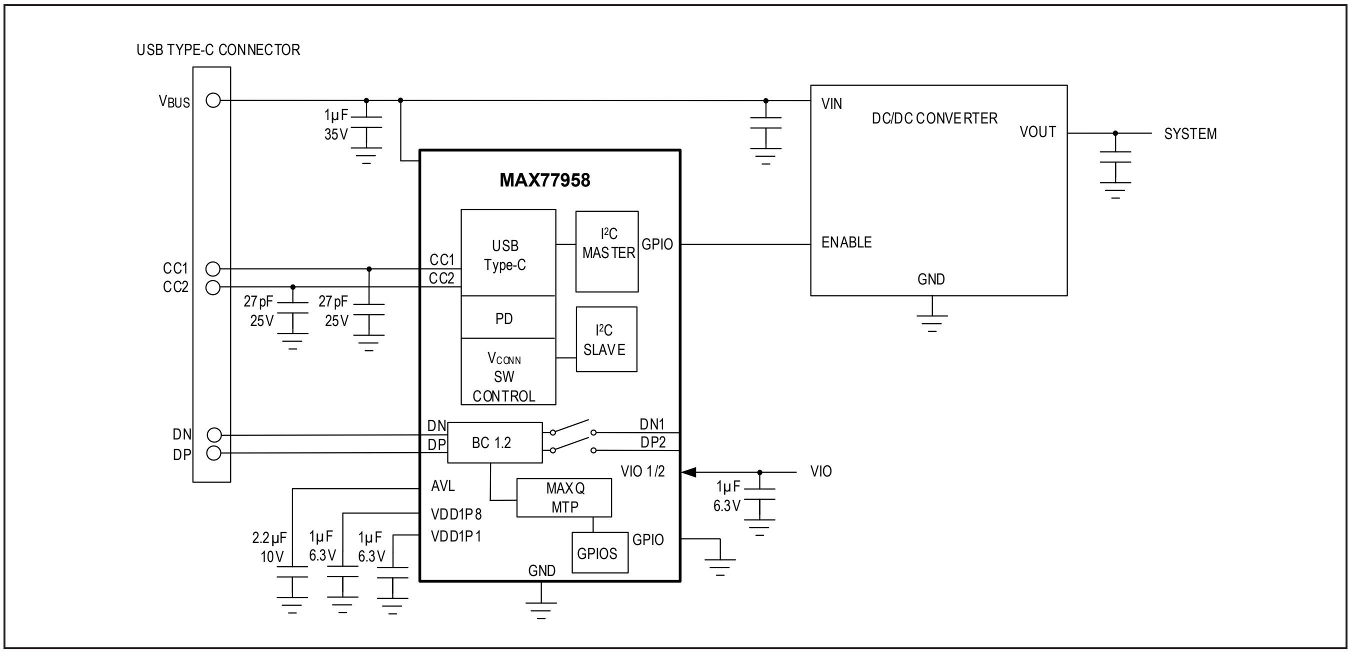

Figure 2. MAX77958 Typical Application Circuit, autonomous DC-DC application, Source: MAX77958 datasheet, Figure 17, Page 80.

MAX17613A circuit protection

The MAX17613A shown in Figure 3 is one of the industries smallest and most robust integrated protection system solutions. It features the adjustable overvoltage and undervoltage lockout protection as well as the reverse-voltage and over-current protection. It also protects the system against positive and negative input voltage faults up to +60V and -65V and features low 130mΩ (typ) R_{ON} field-effect transistors (FETs).

The OVLO and UVLO lockout thresholds can be set using external resistors with an adjustable range of 5.5V to 60V and 4.5 to 59V, respectively.

The current-limit protection feature can be programmed up to 3A, which makes it ideal for controlling inrush current upon startup while charging high capacitance at the output. The current limit threshold is set by connecting a resistor between SETI and GND and can be programmed to act in three different ways under current-limit condition; auto-retry, continuous and latch-off modes.

The MAX17613A also blocks the current flow in the reverse direction and thermal shutdown protection features against excessive power dissipation. There are two outputs; status signals to indicate the different modes of the operation and fault signals $\overline{\text{FLAG}}$ and $\overline{\text{UVOV}}$. They are open-drain active low signals that require external pull-up resistors. The design procedure is followed closely to the datasheet recommendations.

Light-Emitting Diode (LED) fault indicators

Each of the two active low fault indicators $\overline{\text{FLAG}}$ and $\overline{\text{UVOV}}$ on the MAX17613A are connected to red LEDs pulled up to a 5V voltage rail provided by the MAX6765 linear regulator IC.

The resistors in series with the LEDs are chosen to drive the current at the nominal value of 20mA when either $\overline{\text{UVLO}}$ or $\overline{\text{FLAG}}$ is pulled low.

MAX668 Boost converter

The design procedure for the MAX668 boost converter is based on the equations provided in the MAX668/669 datasheet.

The MAX668 is a constant-frequency, pulse-width modulating (PWM) DC-DC converter that is suitable for a range of DC-DC conversion applications such as step-up, single-ended primary inductance converter (SEPIC), flyback and other isolated-output configurations. The internal current mode controller is optimized to achieve maximum efficiency over a range of load conditions by utilizing both PWM operation and Maxim's proprietary Idle Mode™ to minimize operating current under light loads. Other features include soft-start, adjustable current limit and internal operating frequency or synchronization to an external clock source and a wide input voltage range from 1.8 to 28V.

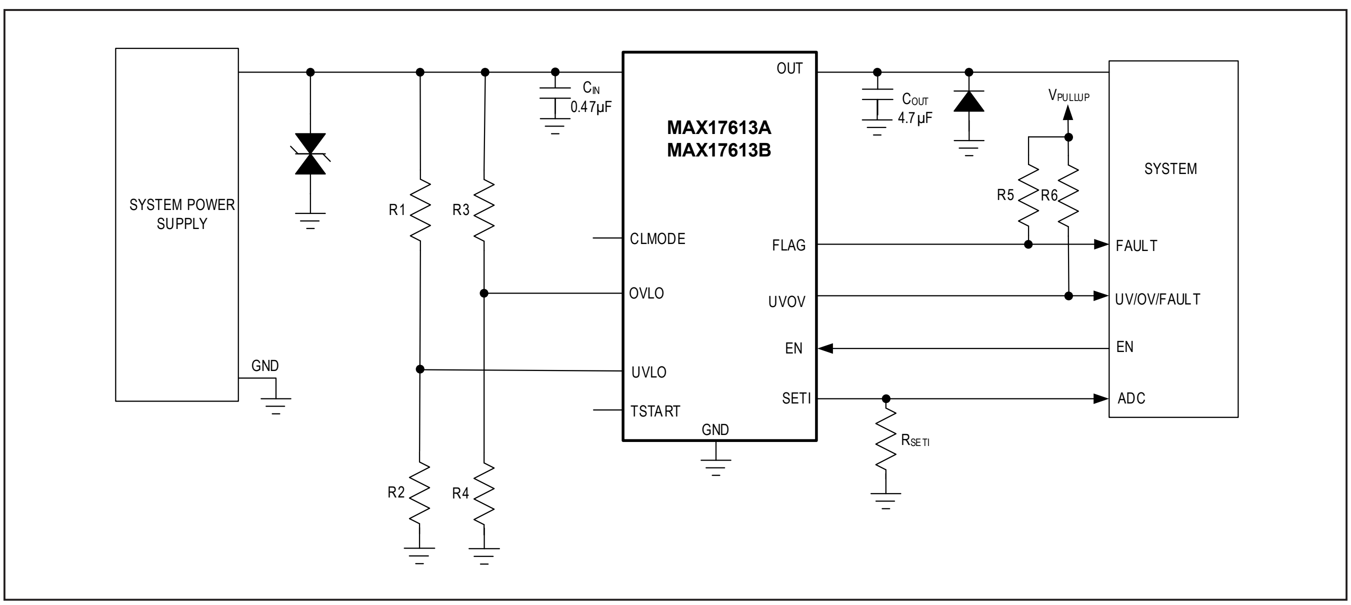

Figure 3: MAX17613A Typical Application Circuit, Source: MAX17613A/B/C datasheet Typical Operating Circuit, Page 2.

Idle Mode is a trademark of Maxim Integrated Products, Inc.

PWM Controller

The heart of the MAX668/MAX669 current-mode PWM controller is a BiCMOS multi-input comparator that simultaneously processes the output-error signal, the current-sense signal, and a slope-compensation ramp (Figure 4). The main PWM comparator is direct summing, lacking a traditional error amplifier and its associated phase shift. The direct summing configuration approaches ideal cycle-by-cycle control over the output voltage since there is no conventional error amp in the feedback path.

In PWM mode, the controller uses fixed-frequency, current-mode operation where the duty ratio is set by the input/output voltage ratio (duty ratio = $(V_{OUT} - V_{IN})/V_{IN}$ in the boost configuration). The current-mode feedback loop regulates peak inductor current as a function of the output error signal.

At light loads, the controller enters Idle mode. During Idle mode, switching pulses are provided only as needed to service the load, and operating current is minimized to provide best light-load efficiency. The minimum-current comparator threshold is 15mV, or 15% of the full-load value (I_{MAX}) of 100mV. When the controller is synchronized to an external clock, Idle Mode occurs only at very light loads.

Current Limit

The current is sensed at the drain of the metal-oxide semiconductor field-effect transistor (MOSFET), which means it senses the input current rather than the output current. The output current limit also depends on the duty cycle or the input voltage since for a boost converter the output current is scaled by the inverse of the input to output relationship, assuming a lossless converter.

$$I_{OUT} = (1\text{-}D)I_{IN}$$

The relationship between the output current limit and the input voltage is shown in the test results.

Soft start

The MAX668/MAX669 feature a “digital” soft start which is preset and requires no external capacitor. Upon startup, the peak inductor increments from 1/5 of the value set by R_{OCS}, to the full current-limit value, in five steps over 1024 cycles of the f_{OSC} or f_{SYNC}.

Soft start is implemented:

1) When power is first applied to the IC.
2) When exiting shutdown with power already applied.
3) When exiting undervoltage lockout.

Figure 4 shows the soft start operation.

Layout considerations (MAX668, MAX17613A, and power MOSFET)

MAX668

Due to high current levels and fast switching waveforms that radiate noise, proper PCB layout is essential. Protect sensitive analog grounds by using a star ground configuration. Minimize ground noise by connecting GND, PGND, the input bypass-capacitor ground lead, and the output-filter ground lead to a single point (star ground configuration). Also, minimize the trace lengths to reduce stray capacitance, trace resistance, and radiated noise. The trace between the external gain-setting resistors and the feedback (FB) pin must be extremely short, as must the trace between GND and PGND.

All the conducting components such as the MAX17613A, inductor, power MOSFET and diode have a power loss factor relative to their conducting resistances and any switching losses. It is important to include enough copper conduction paths so that this heat can be dissipated without overheating the components. Operating temperature limits and thermal conduction rates are taken from the respective component datasheets.

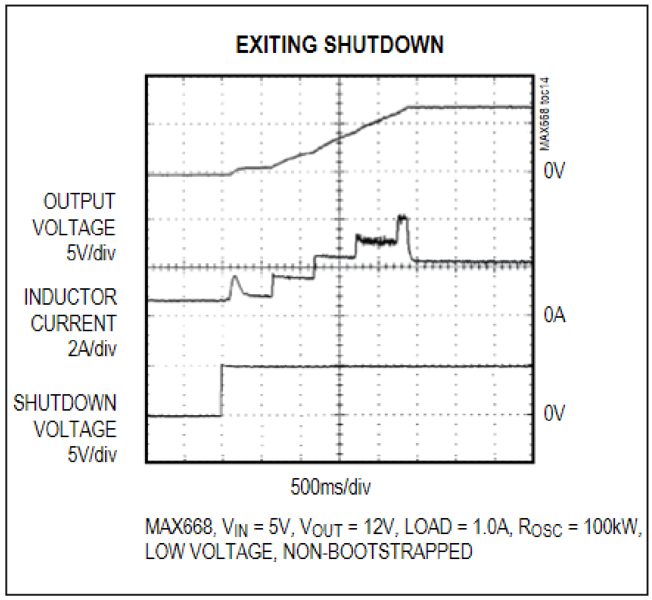

Figure 4: MAX668 soft start feature upon startup, Source: MAX668 Typical Operating Characteristics, Page 7.

Design Resources

Download the complete set of **Design Resources** including schematics, bill of materials, PCB layout, and test files.

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	10/21	Initial release	—