Devices Connected/Referenced	
MAX77958	Standalone USB Type-C and USB Power Delivery Controller
LTC4364-2	Surge Stopper with Ideal Diode
MAX4701	Low-Voltage, Dual DPDT/Quad SPDT Analog Switches in QFN
ADP7142	40 V, 200 mA, Low Noise, CMOS LDO Linear Regulator

Configurable USB-C Power Sink Solution

EVALUATION AND DESIGN SUPPORT

▸ Circuit Evaluation Boards
  ▸ CN0581 Circuit Evaluation Board (EVAL-CN0581-EBZ)
▸ Design and Integration Files
  ▸ Schematics, Layout Files, Bill of Materials

CIRCUIT FUNCTIONS AND BENEFITS

USB-C is an industry standard 24-pin connector system for transmitting data and power over a single cable. In addition to supporting the fastest data rates of USB SuperSpeed (10 Gbps), USB-C (Rev 2.0) supports bidirectional power delivery at several voltages, at power levels up to 100 W. A negotiation process between the power source and sink determines what level the power source provides. The widespread adoption and corresponding low cost of cables, connectors, power supplies, and chargers make USB-C an attractive alternative to dedicated DC power connectors eliminating many proprietary power adapters for a wide range of applications, even when no data connectivity is required.

The circuit shown in Figure 1 is a standalone USB-C power delivery (PD) module that adds USB-C power sink capability to projects and devices, replacing traditional power jacks. Voltages of 5 V, 9 V, 15 V, or 20 V at currents from 0.5 A to 5 A are supported, selected via dual in-line (DIP) switches. A hot-swap surge stopper with ideal diode allows charging of large bulk bypass capacitors, and an enable output enables the downstream load after ramp up is complete, while preventing reverse current during faults. No software control is required for operation; the preloaded firmware configuration reads the DIP switches and sets the power delivery object (PDO) voltage and current modes accordingly. Custom configurations can be optionally programmed via an I^{2}C interface.
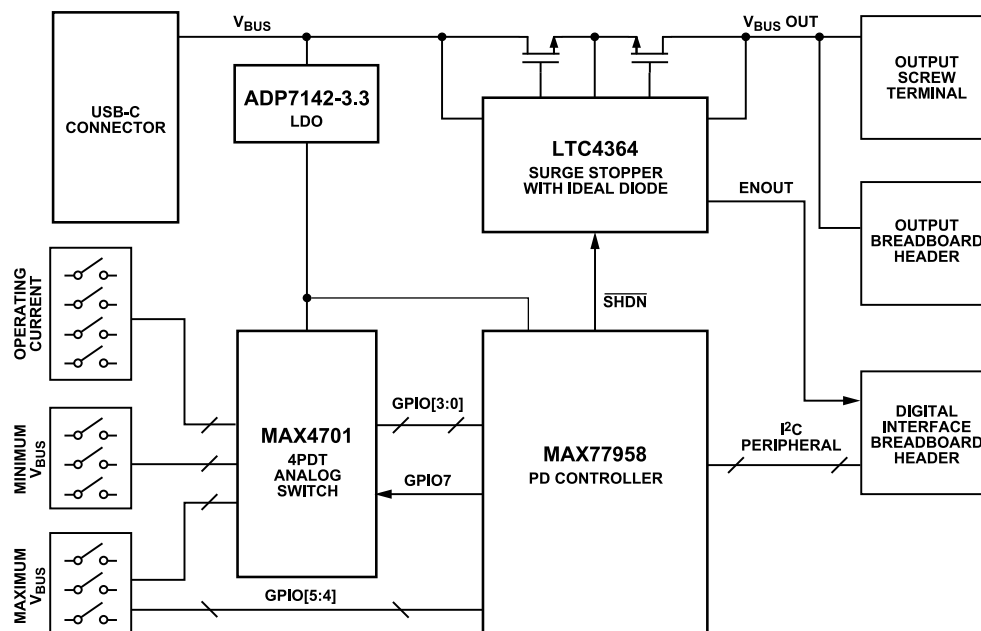

Figure 1. CN0581 Simplified Block Diagram

CIRCUIT DESCRIPTION

USB-C OVERVIEW

USB-C supports high data rates and increased power delivery between electronic devices. It can transfer data as fast as 10 Gbps, while delivering up to 3 A with 5 V (15 W) over standard cables using the basic configuration channel (CC) detection. The USB-C PD 3.0 specification extends operation up to 5 A and 20 V (100 W). By default, a standard USB-C power source provides 5 V at 3 A, although some noncompliant sources may have lower current capability.

The 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 sink can request a higher voltage and inform the source of its current requirements through the PD negotiation process. If the source can meet the sink's requirements, the source's output voltage is set accordingly. These power levels satisfy the requirement of many portable electronic devices, hence the increasing adoption of USB Type-C for charging and general power delivery. The CN0581 allows the user to set the minimum and maximum bus voltage (VBUS), along with the maximum required operating current using the on-board DIP switches. The following PDOs are supported on the CN0581:

▶ 5 V, 9 V, 12 V, 15 V — up to 3 A
▶ 20 V — up to 5 A

Cables, Connectors, and Power Sources

The plugs at both ends of a Type-C cable are identical, allowing for reversible plug-in. Each connector is also reversible, which allows it to be plugged in without worrying about polarity. USB-C cables vary in quality and current carrying capability, a standard cable can typically accommodate bus power up to 60 W at 3 A. In order to achieve 100 W at 5 A, an electronically marked or active cable is required, so be sure that the cable being used is rated for the load current being negotiated. Figure 2 shows the CN0581 plug and receptacle pin configurations.
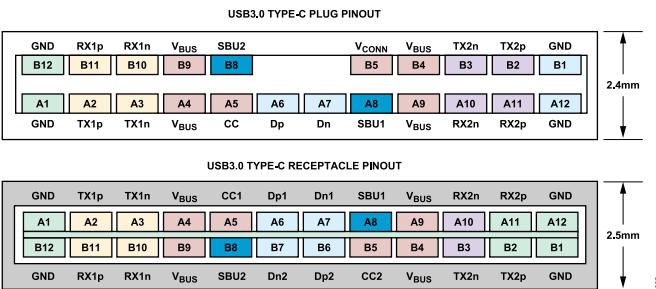

Figure 2. USB Type-C Plug and Receptacle Pinout

The USB power source specifications must be interpreted before use in a given application. Not all power sources provide an intuitive combination of voltages and currents. For example, a high-power laptop charger may provide 20 V at 6.5 A (above the official USB-C standard), 5 V at only 1 A (below the standard), and no support for 9 V or 12 V, as compared to a general-purpose 45 W adapter

which may provide 5 V, 9 V, 12 V, and 15 V at 3 A (adheres to the USB-C standard) and 20 V at 2.25 A (below the standard). So it is important to validate the USB-C power sources capabilities when connecting a USB-C sink device negotiating for a particular power level.

USB TYPE-C CC DETECTION AND PD MESSAGING

The core of the CN0581 is the MAX77958 standalone USB Type-C and USB power delivery controller.

This device detects connected sources or sinks by first using USB Type-C CC detection, followed by power delivery protocol using USB PD messaging. The MAX77958 protects against overvoltage and overcurrent, detects moisture, and prevents corrosion on the USB Type-C connector. It is compliant with USB Type-C Version 1.3 and PD 3.0, but also has a D+/D- USB switch and battery charging (BC) 1.2 detection to support legacy USB standards.

The CC detection process detects cable presence, orientation, as well as power role and current requirements for the initial 5 V supply voltage. CC detection is new to USB version 1.3 when compared to the legacy USB-C standard in which 5 V 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. Table 1 shows the different CC detection configurations. After CC detection, the PD negotiation process continues. If there are multiple valid PDO combinations, the highest power source PDO is requested.

Table 1. USB-C Configuration

USB-C Connector	Device Type	Cable Orientation	Source Current Capability
USB-C Plug	CC = Logic High (Source) CC = Logic Low (Sink)	N/A	CC_voltage < 0.15 V: No connection 0.25 < CC_voltage < 0.61 V: 0.5 A 0.7 < CC_voltage < 1.16 V: 1.5 A 1.31 V < CC_voltage: 3 A
USB-C Receptacle	N/A	CC1 = Logic Low (not flipped) CC2 = Logic Low (flipped)	

Another feature of USB-C is cold-plugging, namely the VBUS voltage is provided only after successful end-to-end detection is completed. This feature makes CC detection mandatory in USB-C applications, and the MAX77958 transparently handles all cold-plugging and CC operations.

The CN0581 uses the MAX77958 in sink mode to determine the capabilities of the connected source device and optimize power into the surge stopper/ideal diode circuit, as shown in Figure 3.
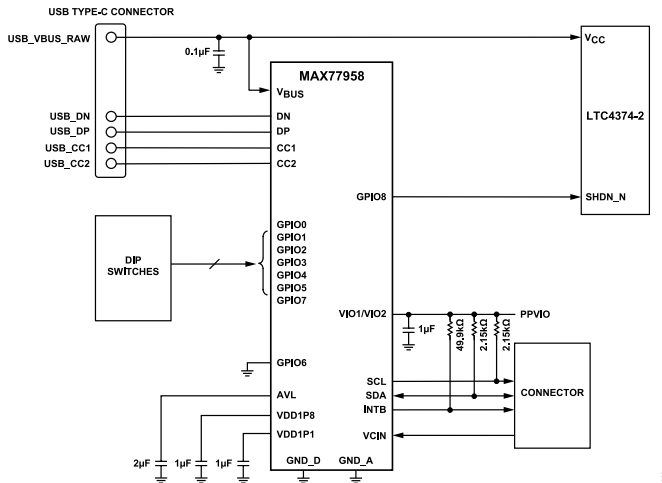

Figure 3. MAX77958 PD 3.0 Controller Block Diagram

The MAX77958 has an I^{2}C controller interface that can be pre-programmed with custom firmware to 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 device also has with a separate I^{2}C peripheral interface through which the system can read/write and configure internal registers. The MAX77958 has nine configurable GPIOs that can be used for detection, as interrupts, as the enable/disable pin for external devices, or as ADC inputs.

PDO Selection

The PDO minimum voltage, maximum voltage, and current requirement are set through DIP switches (Table 2 and Table 3, respectively). Each DIP switch has an open solder blob jumper in parallel such that the board may be configured permanently.

Ten switches are required to select all modes, but the MAX77958 has only seven GPIOs remaining for this function. A MAX4701 dual double pole/double throw (DPDT) switch is used to multiplex the DIP switch signals, as shown in Figure 4. The custom firmware programmed into the CN0581 sequences through all switches and sets the PDO modes accordingly.
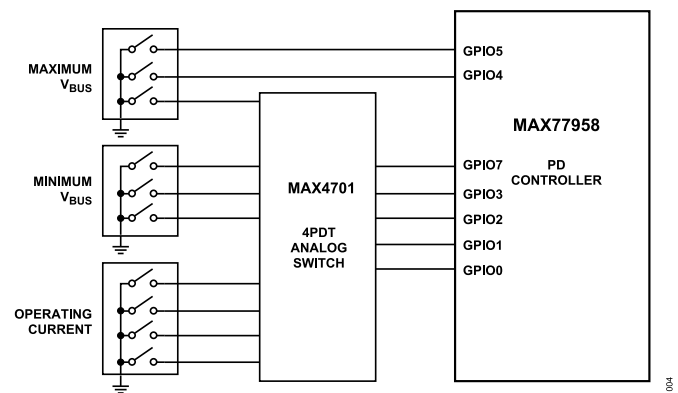

Figure 4. Implementation of MAX4701 Switch for Multiplexing with MAX77958 GPIO

Table 2. Multiplexing Switch Settings for Different VBUS Values

Min/Max VBUS	SW1	SW2	SW3
5 V	OFF	OFF	OFF
9 V	OFF	OFF	ON
12 V	OFF	ON	OFF
15 V	OFF	ON	ON
20 V	ON	X	X

Table 3. Multiplexing Switch Settings for Different Operating Current

Operating Current	SW1	SW2	SW3	SW4
0.5 A	OFF	OFF	OFF	OFF
1 A	OFF	OFF	OFF	ON
1.5 A	OFF	OFF	ON	OFF
2 A	OFF	OFF	ON	ON
2.5 A	OFF	ON	OFF	OFF
3 A	OFF	ON	OFF	ON
3.5 A	OFF	ON	ON	OFF
4 A	OFF	ON	ON	ON
4.5 A	ON	OFF	OFF	OFF
5 A	All Other Combinations			

The multiplexing switch can be configured in several different configurations for 5 A operating current. For a complete list, visit the CN0581 User Guide.

SURGE STOPPER WITH IDEAL DIODE

With USB Type-C comes new challenges in system protection. While PD negotiation and the single, standardized, reversible connector mitigate several mechanical and cable fault conditions, an LTC4364-2 hot-swap and ideal diode controller provides protection from high power fault conditions, along with robust power-up into large bulk bypass capacitors.

The surge stopper section of the circuit consisting of Q1, driven by the LTC4364-2's HGATE control pin, provides several functions. It qualifies the input voltage, only turning on when the input voltage is between 3.5 V and 21.8 V. Once this condition is met, the HGATE

current source is enabled, ramping the output voltage into up to 1000 μF of bulk bypass capacitance.

Q2, driven by the LTC4364-2's DGATE pin, functions as an ideal diode, preventing reverse current flow in the event the output voltage rises above the USB-C source's voltage due to a fault condition in the power sink circuit, as may occur if the circuit can accept power from multiple sources. Figure 5 shows the surge stopper designed around LTC4364-2 surge stopper with ideal diode control.
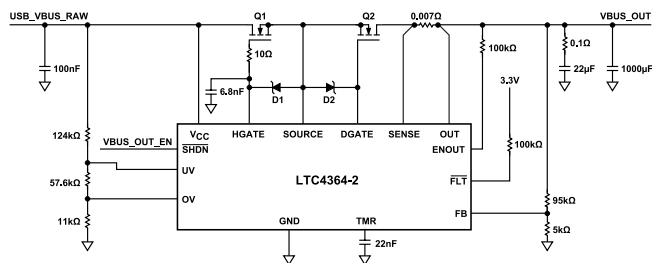

Figure 5. Surge Stopper Circuit

Overcurrent Fault

The LTC4364-2 features an adjustable current limit that protects against excessive load current and short circuits. During an overcurrent event, the HGATE pin of LTC4364 is reduced to limit the voltage across the 7 mΩ sense resistor between the SENSE and OUT pins to 50 mV, corresponding to 7.1 A nominal. Upon entering current limit, a current begins charging the 22 nF TMR capacitor according to Equation 1:

$$I_{TMR} = 10\mu A + 3.36[\mu A/V] \times (USB\_VBUS\_RAW - VBUS\_OUT - 0.5V) \tag{1}$$

where:
I_{TMR} is the TMR pin current.
USB_VBUS_RAW is the voltage input from the USB-C source.
VBUS_OUT is the voltage output from the LTC4364-2.

The timer expires when the capacitor voltage reaches 1.35 V, after which HGATE is pulled low, turning Q1 off. This corresponds to a time of approximately 3 ms when first entering current limit, dropping to 400 μs if a 20 V VBUS_OUT is short-circuited. After the overcurrent fault condition has been removed and a cool down period has transpired, the HGATE pin is allowed to pull back up and turn on Q1.

Input Overvoltage Fault

At power-up, if the LTC4364-2 OV pin voltage is higher than its 1.25 V threshold before the 100 μs internal power-on-reset expires, or before the input undervoltage condition is cleared at the LTC4354-2 UV pin, the HGATE pin will be held low until the OV pin voltage drops below its threshold. The nominal value set for the CN0581 input overvoltage fault is 21.8 V.

Input Undervoltage Fault

When the voltage at the LTC4364-2 UV pin is below its 1.25 V threshold, the surge stopper is off. Once the UV pin voltage rises above the UV threshold plus the UV hysteresis (50 mV nominal),

the HGATE pin is allowed to pull up without going through a timer cycle. The nominal value set for the CN0581 input undervoltage fault is 3.5 V.

Output Overvoltage Fault

The LTC4364-2 limits the voltage at the OUT pin during an output overvoltage fault. If the voltage at VBUS_OUT is higher than 24.5 V, set by the FB pin resistors; for longer than the timeout period set by the timer capacitor, an output overvoltage fault is detected, and the surge stopper turns off. After the output overvoltage fault condition has been removed and a cool down period has transpired, the surge stopper of LTC4364-2 turns on again.

POWER ARCHITECTURE

Figure 6 shows the complete power architecture of the CN0581. An ADP7142 provides a regulated 3.3 V for the system I/O voltage (VIO), which sets the GPIO and I^{2}C bus logic levels.
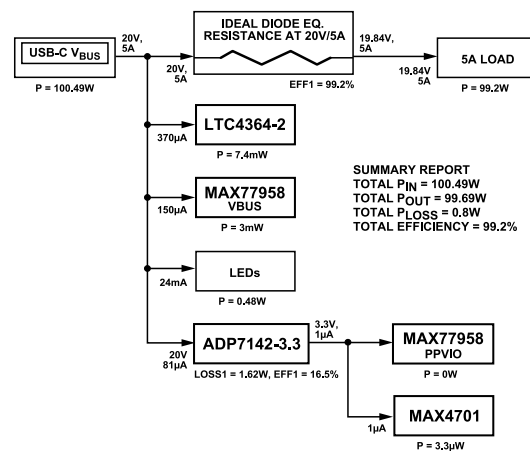

Figure 6. CN0581 Power Tree

The total power loss measured on the board at 20 V with a 5 A load is less than 1 W, and the voltage drop across the ideal diode is about 0.16 Ω at the same load of 5 A.

COMMON VARIATIONS

For applications with a fixed set of PDO configurations, the MAX77958 firmware can be customized and the switches can be removed if the number of configurations can be handled on the MAX77958 GPIO pins directly. See the MAX77958 Customization Script and OPCode Command Guide for more information.

The CN0581 has the LTC4364-2 input OV/UV thresholds, current limit, and hot-swap ramp rate set to accommodate the entire 5 V to 20 V range at maximum current, and a maximum capacitance of 1000 μF. All of these parameters can be adjusted by changing the appropriate configuration components, refer to the LTC4364-2 data sheet.

In applications in which the power adapter and application circuit are well-matched, the LTC4364-2 can be eliminated entirely. If the circuit has an enable input, the VBUS_OUT_EN control signal can be used to hold the circuit off until VBUS is stabilized.

To interface ENOUT pin to a microcontroller, a comparator such as the ADCMP350/ADCMP354/ADCMP356 can be used to obtain a logic level from 2.25 V to 5.5 V with any input from 0 V to 22 V.

CIRCUIT EVALUATION AND TEST

This section outlines the general setup and circuit evaluation procedure for CN0581. For complete step by step instructions, refer to the CN0581 User Guide.

EQUIPMENT NEEDED

▸ EVAL-CN0581-EBZ

▸ USB-C power source capable of delivering 100 W

▸ USB Type-C cable (rated for 20 V and 5 A)

▸ DC2132A Constant Voltage, Constant Current Bench Supply (used as a typical example load)

▸ 8.5 Ω, 20 W power resistor

▸ Additional 220 µF capacitor (for emphasizing ramp-up current)

▸ Voltmeter or multimeter

▸ 4-channel scope

▸ Current probe

GETTING STARTED

1. Configure the EVAL-CN0581-EBZ:

    a. Connect the CN0581 jumper to select the 3.3 V logic voltage.

    b. Set the CN0581 PDO minimum and maximum bus voltage to 15 V.

    c. Set the CN0581 PDO maximum current to 3 A.

    d. Connect the 220 µF capacitor at the output of CN0581, observing polarity.

2. Connect the EVAL-CN0581-EBZ output to the DC2132A input terminals.

3. Set the DC2132A output to 12 V.

4. Add an 8.5 Ω resistor to the output of DC2132A.

5. Connect the ENOUT pin from the EVAL-CN0581-EBZ to the EN/UV pin of the DC2132A's buck converter.

6. Connect the EVAL-CN0581-EBZ to the USB-C source via the USB cable.

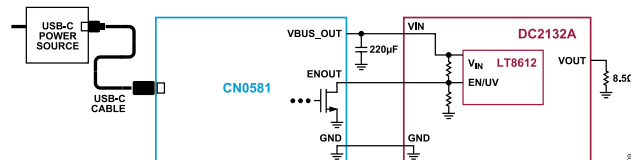7. The complete setup should look like the block diagram shown in Figure 7.

Figure 7. CN0581 Test Setup with DC2312A Bench Supply

TEST RESULTS

Figure 8 and Figure 9 show the results of the voltage ramp-up, PD negotiation process, current during ramp-up and operation, and the enable signals. Upon connection of the USB-C power source, the following events occur:

1. USB_VBUS_RAW rises to 5 V, the default output of the source.

2. The CN0581 negotiates with the source (in this case 15 V/ 3 A PDO), and USB_VBUS_RAW output rises to 15 V.

3. The MAX77958 drives the VBUS_OUT_EN signal high, enabling the LTC4364-2.

4. The LTC4364-2 HGATE charge pump turns on, ramping the output voltage up. During this time, the current into the 220 µF bulk capacitance is a constant 600 mA.

5. Once the hot swap MOSFET is fully enhanced, the LTC4364-2 ENOUT signal goes high-impedance, enabling the DC2132A.

6. The DC2132A output rises to 12 V and the load resistor draws 1.4 A, corresponding to 1.2 A from VBUS_OUT.
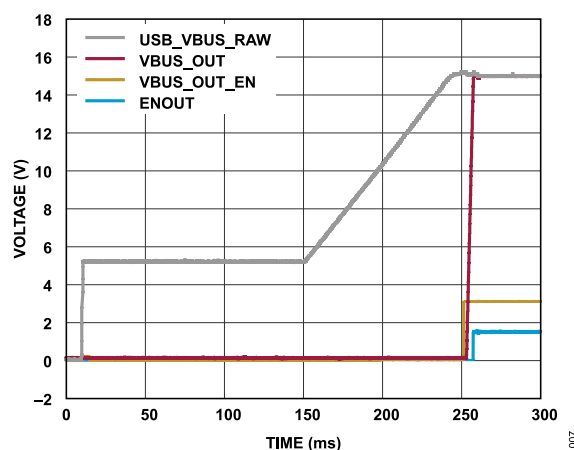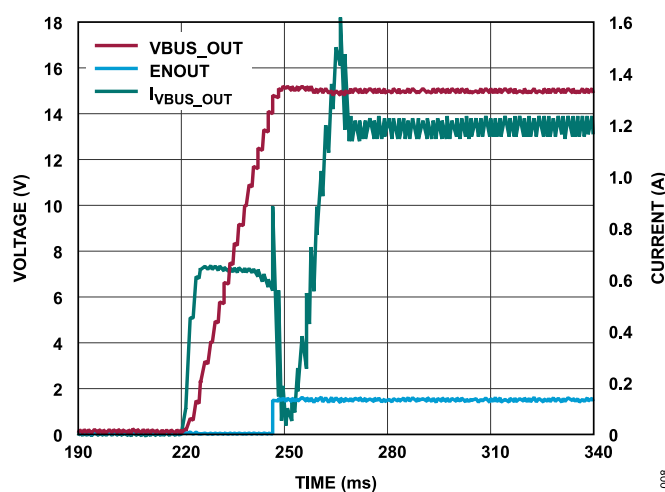

Figure 8. CN0581 Power-up Sequence

Figure 9. DC2132A Power-up Sequence

LEARN MORE

CN0581 Design Support Package

Application Note 2736, *"Understanding, Using, and Selecting Hot-Swap Controllers."* Analog Devices.

Khare, Sagar, *"Simplify Your USB-C PD Design Using a Standalone PD Controller."* Analog Dialogue, Vol 57, May 2023.

MAX77958 Customization Script and OPCode Command Guide. Analog Devices.

O'Sullivan, Marcus, *"Understanding Hot Swap: Example of Hot-Swap Circuit Design Process."* Analog Dialogue, Vol 42, May 2008.

"USB-C Power Delivery Data Lines Demand Enhanced Protection." Analog Devices.

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USB.org, *"USB Power Delivery Specifications."* 2023.

DATA SHEETS AND EVALUATION BOARDS

MAX77958 Data Sheet

MAX77958 Evaluation Board

LTC4364-2 Data Sheet

LTC4364-2 Evaluation Board

MAX4701 Data Sheet

ADP7142 Data Sheet

ADP7142 Evaluation Board

REVISION HISTORY

10/2023—Revision 0: Initial Version