APPLICATION NOTE

How to Test USB Power Delivery Over the Type-C Connector

KEYSIGHT

Overview

USB Type-C, or USB-C, has become a ubiquitous and widely adopted interface in modern electronic devices. The connector supports a smaller form factor, higher data rates, more power capabilities, and flexible connectivity with other protocols. There are several key USB Type-C focus areas, such as connecting devices, managing power, and ensuring valid data transmissions. The USB Type-C connector provides reversibility for ease-of-use and dynamic power of up to 240 W with USB4 protocol. It is backward compatible with USB 2.0, USB 3.2, USB 3.1, and USB4. The alternate mode supports DisplayPort, HDMI, and PCIe® protocols for many new and future devices.

Design and test engineers face several challenges as they integrate USB Type-C into their products while ensuring interoperability and test compliance. As the USB Type-C compliance test standard has become more complex, successful testing requires highly accurate and standard-compliant test instruments, software, and fixtures.

This application note covers various aspects of the challenges and solutions for USB power delivery over Type-C cables, including new USB4 and USB4 Version 2.0 compliance test requirements to support power delivery modes.

USB Type-C Power Delivery

Figure 1 illustrates the USB Type-C power delivery (USB-PD) standard using USB4 extended power range (EPR) protocol can provide up to 240 watts (48 V, 5 A) for dynamic power and charging of different devices. The USB power delivery's intelligent and flexible system-level power management supports bidirectional power that can switch directions for the connected provider (sourcing power) and consumer (sinking power) devices.

These new capabilities create a more significant challenge for design and test engineers who are striving to ensure the interoperability of their USB products by performing USB Implementers Forum (USB-IF) standard conformance tests.

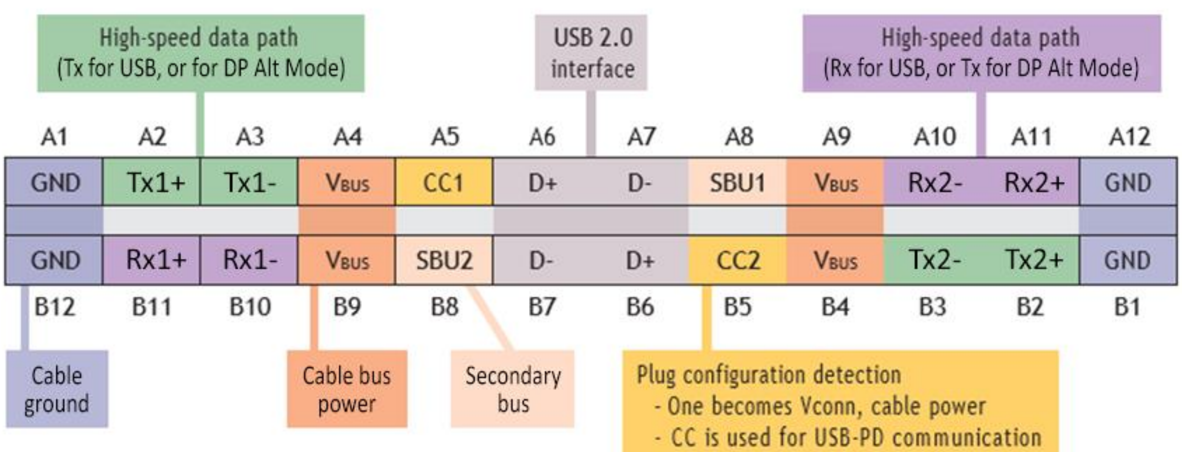


Figure 1. USB Type-C pinout USB-PD primarily uses USB bus voltage (VBUS), Vconn, and configuration channel (CC) pins

How power delivery works

The USB connection initialization begins with power delivery. The power delivery setup learns the functionality of the connected cable through an electronic connection between the power delivery circuit and any full-featured Type-C cable, which includes an e-Mark chip. The e-Mark chip provides cable configuration information and is recognizable electronically and configured to its current carrying capability (3 A or 5 A), performance (USB 2.0 or USB 3.1, Gen 1, or Gen 2, as well as USB4 Gen 3 and Gen 4), and vendor identification (USB Type-C cable ID function).

Following the cable recognition, the power delivery circuit, and the connected device use the dedicated configuration channel (CC1 / CC2) lines to send and receive biphase mark coding (BMC) messages to begin power negotiation.

USB PD now supports three types of charging models:

- Fixed voltage model charges use a set of defined fixed value voltages operating either in the standard power range (SPR) at 5, 9, 15, and 20 V or enhanced power range (EPR) with additional voltages of 28, 36, and 48 V.
- Programmable power supply (PPS) model charges use a set of defined ranges of voltage operating only SPR mode from 3.3 to 21 V.
- Adjustable voltage supply (AVS) model charges using a set of defined ranges of voltage operating only in an extended power range (EPR) model from 15 to 48 V.

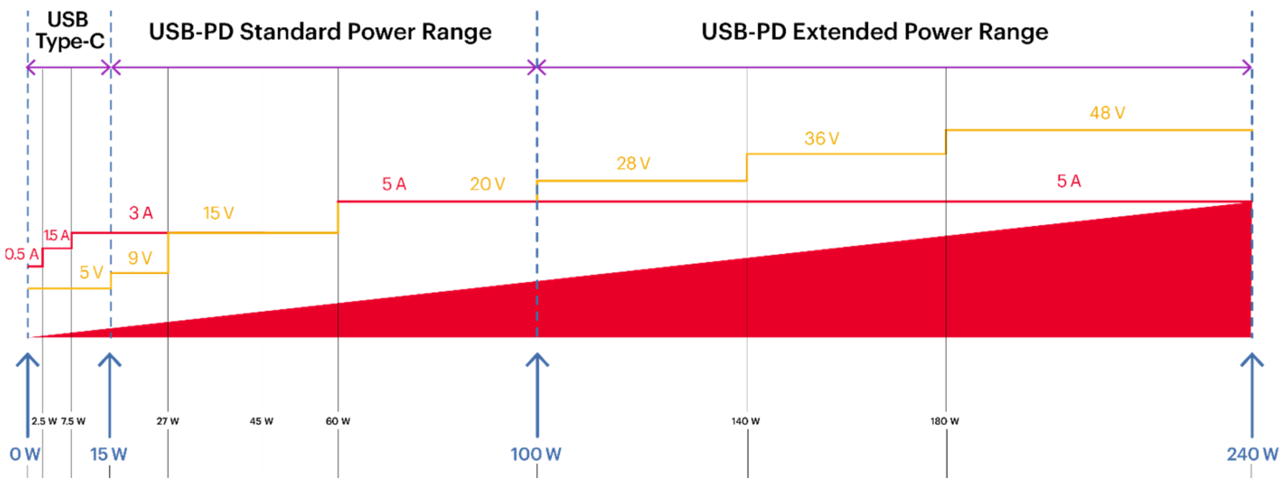


Figure 2. USB-PD ranges in the fixed voltage model, from the required power capabilities of a Type-C connector to the optional EPR

The power negotiation process between the connected devices determines the type of charging models. If the source or provider can support the programmable power supply and adjustable voltage supply charging models, it will advertise or declare its capability in the augmented power data object (APDO). However, if limited only to the fixed voltage charging model, the source will advertise its capability in the power data object (PDO). The sink or consumer device will communicate its required power to the power source. The sink device typically requests a specific level of electrical power with variables up to 5 A and 21 V and establishes an initial power contract in SPR mode.

If the source, sink, and cable support the EPR mode, the devices may enter a new power negotiation for a higher power level above 100 W, up to 240 W. Once the EPR mode power establishes the contract, the sink device is required to maintain a regular cadence of communications with the source device to remain in EPR mode operation. The USB power delivery dynamically manages the power allocations, adjusting the voltage and current, and establishes provider / consumer roles for all connected devices.

When a device charges, all other connected devices must negotiate the required power. Devices can renegotiate power if another device requires additional power. Power delivery can also optimize to a lower battery voltage and higher charging current, making the recharging time much faster. In addition to the power management of connected devices, the power delivery also manages power to support Type-C alternate modes (ALT).

The higher and dynamically variable power provided by USB Type-C power delivery requires more verification and testing by design engineers to achieve compliance. In addition to managing bidirectional power for a device, the CC1 / CC2 line signals must be verifiable for proper protocol transmission for changing power and managing ALT modes. In contrast, other D± and ALT mode signals are active. Type-C power delivery is dynamic and has a range of power configurations. Additional challenges are evolving specifications for USB 2.0, USB 3.1 Gen 1 and Gen 2, as well as USB4 Gen 3 and 4, and power delivery compliance. These multiple configurations make Type-C device test validation much more challenging than the traditional USB test.

Test Challenges

Power delivery specifications continue to evolve. The power, physical (PHY) layer, and protocol layer remain the key test categories for compliance testing. Important test parameters are the numerous voltage levels, device charging, cable functionality, and determination of provider versus consumer device status. A clear understanding of Type-C device compliance test requirements, the instrumentation, and the software required to achieve reliable, accurate measurements ensures the best and most cost-effective results.

Power and charge of devices

The power negotiation performs the process either via CC1 / CC2, depending on the cable orientation. Verifying and applying the correct voltage and current requires monitoring the CC line for proper protocol and measuring the generated voltage and currents. You can accomplish this by monitoring the CC1 / CC2 line with a 300 kHz signal to test using an oscilloscope to analyze the eye diagram. Analysis and adjustment of the CC line code can be challenging because cable voltages are continually changing, and crosstalk may also be present.

Thorough testing is also necessary to ensure fast charging of device batteries — up to 48 V / 5 A / 240 W to ensure the adaptive fast charging is safe and reliable. One key challenge for the power delivery layout verification is the effects of noise, ripple, and switching, especially with 10 to 48 V signals. Figure 3 illustrates the power delivery integrity measurements you can make with an oscilloscope:

- Measure the supply drift.
- Track the periodic and random disturbances (PARD) — noise, ripple, and switching transients on power rails.
- Compare the static and dynamic load response.
- Monitor the programmable power rail response.
- Measure and monitor the high-frequency transients and noise.
- Regulate the product's electrical validation at extended temperatures.

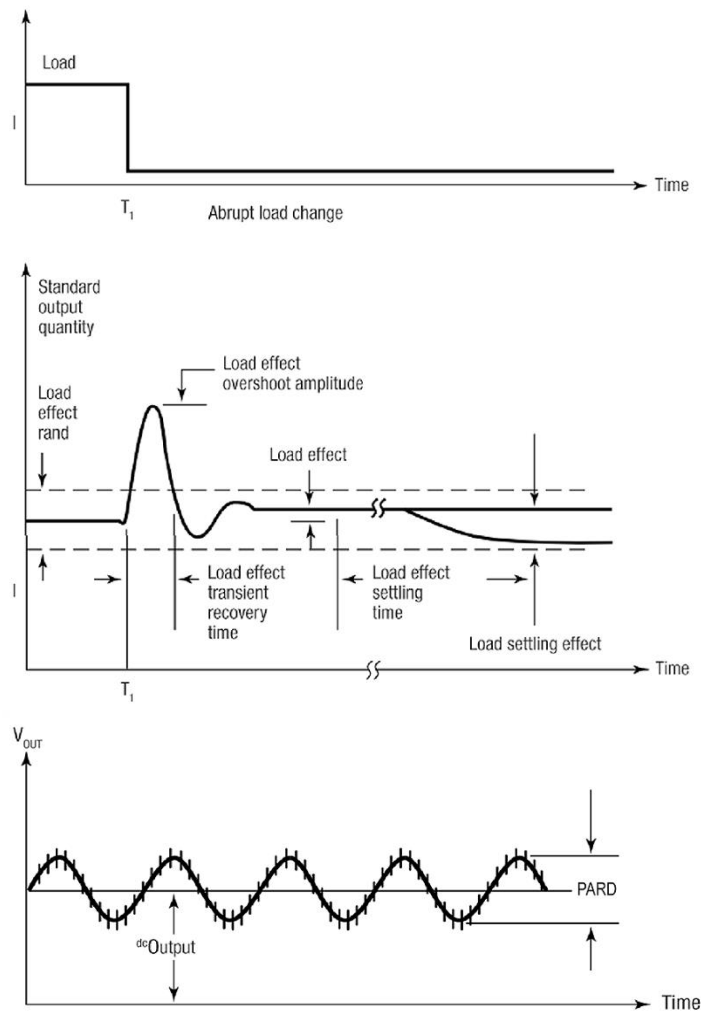


Figure 3. USB power delivery typical power integrity measurements — load response and PARD

Cable functionality

USB Type-C cables require additional testing because the power delivery features provide much more functionality. Each cable configuration scenario requires testing — including varying bidirectional power, USB data transfer, provider / consumer role assignment, and ALT modes.

Testing begins with verification of the active Type-C cable by testing voltage levels to and from the E-mark chip. Verifying whether the dual role port (DRP) device is sourcing or sinking power is important. You can use an oscilloscope, current probes, power supplies, and fixtures to measure rise time, fall time, voltage, and high / low levels.

The power delivery compliance verification includes testing of other low-speed lines such as a secondary bus (SB), USB bus voltage (VBUS), and ground (GND). The CC line (shielded pair) presents a risk of crosstalk when combined with the unshielded D ± lines — with a potential for up to 240 W power lines. The power delivery is constantly negotiating power to devices, and the USB bus voltage and D ± are changing while devices try to decode the CC line. This process creates a very challenging configuration to operate.

USB Type-C Power Delivery Solutions

A complete solution for physical layer USB-C and USB-PD testing includes an oscilloscope, passive probes, a current probe, USB-PD protocol software, coupons / fixtures, and a power delivery controller. You need an oscilloscope of 500 MHz or more with a long record length to capture the entire packet.

The Keysight D9110USBP USB power delivery software for Keysight Infiniium oscilloscopes helps developers with real-time protocol triggering and debugging of the power delivery lines. The D9110USBP provides an easy way to debug the Type-C constant current biphase mark encoded 300 kbps signal. This process includes advanced USB triggering, time-correlated decode trace, protocol lister / tabular window view, and USB power delivery search capability.

Although this application uses predominantly DC signals, the AC characteristics are an important consideration. A high enough oscilloscope bandwidth is a requirement to make the AC measurements. When analyzing the 5 V DC supply signal, it is best to use a probe offset to see transients on the signal. The use of a DC block may miss DC and low frequency content.

Recommended test components

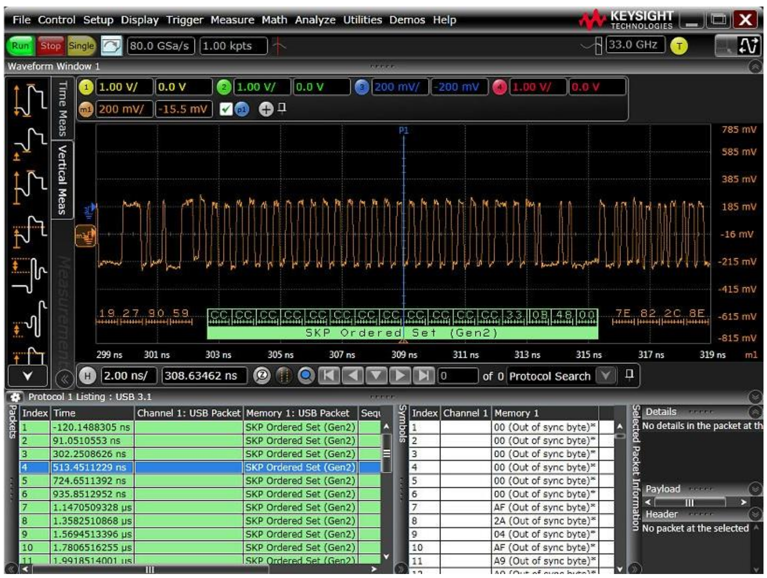
- Keysight N2873A passive probes (two each) for CC1/2 and a VBUS test
- Keysight 1147B current probe for load current
- Keysight N6764A (300 W) or N6786A (80 W) high-performance DC source module and the Keysight N3303A DC electronic load module
- Power delivery controller and associated software and coupons

The Keysight N7020A power rail probe for the analysis of the power delivery of 5 V, 10 V, or 20 V key features:

- Provides 1:1 attenuation for low noise.
- Measures ± 24 V offset support power rails up to 24 V to cover the 20 V power delivery.
- Maintains 50 kΩ input impedance at DC ensures low DC loading of the power rail measurement.
- Provides 2 GHz bandwidth for capturing high-frequency noise and transients that can adversely affect clock and data jitter.

The Keysight N7018A Type-C test control fixture helps developers test and debug low-speed signals such as CC1, CC2, VBUS, and sidebar use pins 1 and 2 (SBU1, SBU2). The fixture connects to the high-speed fixture through a captive Type-C cable. This process enables developers to separate the USB data signals from the downstream USB devices for system diagnosis and control. It also enables signal probing with a high-impedance passive probe for in-depth signal analysis.

The Keysight N7019A Type-C active link fixture provides fast and easy access to test, debug, and decode your Type-C active link. With the Keysight protocol and decode software, you can now access, debug, and decode VBUS, USB-PD, USB 2.0, USB 3.2, USB4 SB, USB4 10G, and USB4 20G on an active link.



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