APPLICATION NOTE

How to Test USB Type-C Alternate Mode

KEYSIGHT

Overview

USB Type-C (or USB-C) is a ubiquitous and widely adopted interface in modern electronic devices. The connector supports a smaller form factor, higher data rate, more power delivery capabilities, and flexible connectivity with other protocols. Key USB Type-C focus areas include connecting devices, managing power, and ensuring valid data transmissions.

The USB Type-C connector provides reversibility for ease of use, dynamic power up to 240 W with USB4 protocol, backward compatibility (USB 2.0, USB 3.2, USB 3.1, and USB4), and alternate mode to support DisplayPort, HDMI, and PCIe® protocols for many new and future devices.

Design and test engineers face several challenges when integrating USB Type-C into their products while ensuring interoperability and test compliance. As the USB Type-C compliance test standard grows 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 testing the USB Type-C alternate modes, including the latest DisplayPort, HDMI, and PCIe® protocols that can be carried over the Type-C connector and cables.

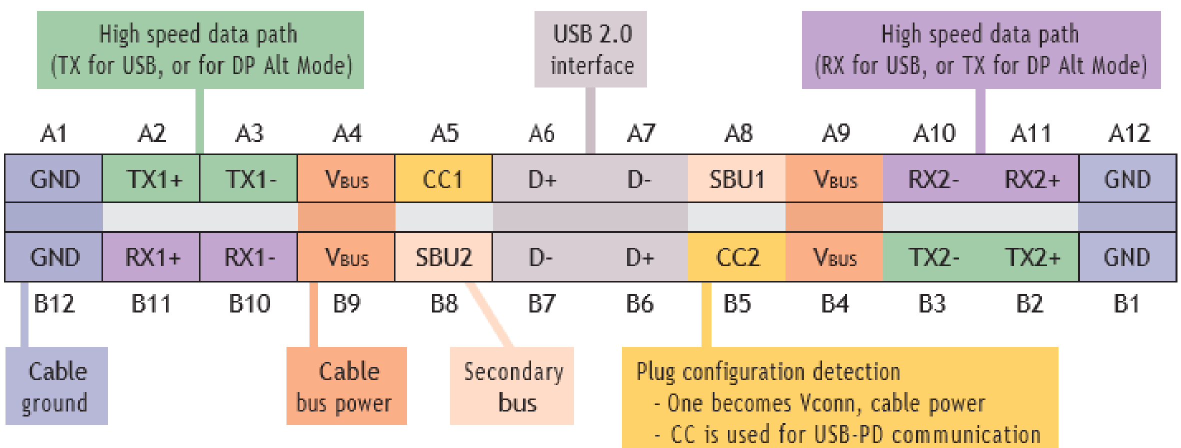

Figure 1. USB Type-C pinout features a symmetrical and reversible structure

USB Type-C Alternate (Alt) Mode

USB-C technology enables alternate modes that use the USB Type-C connector and cables. This feature enables the configuration of different USB-C connector pins to support interfaces that are not typically associated with USB-C.

USB-C and USB Power Delivery (USB-PD) provide a discovery process to find alternate modes on connected USB devices and the procedure for changing modes. To maintain consistency and uniformity, USB-C also outlines specific mandates that alternate modes must follow.

One such Alternate Mode specified by the USB-C standard is DisplayPort is referred to as “DisplayPort Alt Mode” on the USB-C connector. The DisplayPort (DP) Alt Mode standard enables all four USB-C high-speed differential pairs to support four DP Main Link lanes. These lanes facilitate the transmission of DP signals between a source and a sink device or between any upstream / downstream-facing DP device with the same performance capability as native DP connectors and cabling.

While USB4 supports the tunneling of DP, USB 3.x, and PCIe®, conflicts in the sideband signaling between the two protocols prohibit combining USB4 support with DP Alt Mode. USB4 hosts and hubs may enter DP Alt Mode with USB-PD-capable downstream devices or tunnel DisplayPort over USB4, provided the downstream device supports it.

How Alt Mode Works

After establishing the initial end-to-end USB Type-C connection, the device detects the cable orientation and acknowledged provider / consumer roles. The USB Type-C power delivery circuit begins negotiating and managing power for all connected devices. Power delivery negotiation enables devices to specify the power required and request adjustments to that power when needed for different functions. During the negotiation and discovery process, a device can request the use of the Alt Mode for its unique protocol requirements. The non-USB data is transmitted on repurposed pins for alternate data protocols in the USB Type-C cable.

The Type-C connection has four data lanes across eight pins (TX1±, RX1±, TX2±, and RX2±) which can carry USB4, USB 3.2, USB 2.0, DisplayPort, Thunderbolt, PCIe® data, or an alternate data protocol. The four high-speed transmit and receive (TX / RX) lanes, two sideband pins (SBU1 and SBU2), and CC1 or CC2 are available during Alt Mode transmissions. The D± pins are always reserved for USB 2.0 data transmissions. The new connected configuration (CC1 / CC2) channel pin provides power to the active cable.

The power delivery circuit uses voltage-level messages through the CC1 / CC2 channel to configure the alternate protocol modes. Alt Mode is flexible and allows devices to dynamically reassign USB Type-C pin functionality by communicating with the power delivery CC1 / CC2 channel. For example, a device could start up as USB 3.1, then switch to DisplayPort 1.3.

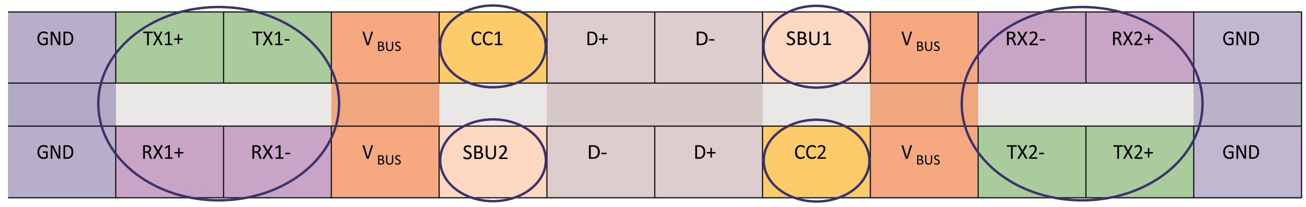

Figure 2. Circled pins are used for Alt Mode

In Alt Mode, the Sideband Use (SBU) lines become active. The table below shows the SBU line function for the different Alt Mode technologies.

Alt Mode technology	SBU line function
DisplayPort	AUX ±
HDMI	Ethernet and Audio Return channels (HEAC+, HEAC-) Hot plug detect functionality (HPD)
Thunderbolt	Low-speed Rx and Tx lines (LSRX, LSTX)

Enabling USB alternate protocols to work with the USB Type-C connection has simplified device interconnection for consumers. However, designing, integrating, and validating devices with the alternate protocols, USB data transfers, and dynamic power will require extensive characterization and a more intense compliance regimen.

Alt Mode Test Challenges

The number of tests required during the design and verification of USB Type-C devices using the alternate protocol is much greater than for USB Type-C conformance testing alone. There are key test challenges for engineers validating these devices:

- Testing and verifying the power delivery lines to discover and configure the Alt Mode protocol
- Testing Alt Mode specifications
- Testing Alt Mode cable assemblies

Test and verify the power delivery CC1 / CC2 line to discover and configure the Alt Mode protocol

The DisplayPort AUX lines connect to SBU1 / 2, and the hot plug detect adds to the power delivery's CC1 / CC2 line as a packet, which is converted to a command. The inability to easily change the content of the hot plug detect packet makes it challenging to perform any automated commands to simulate and verify the typical DisplayPort setup. Developers must control the information passed to the power delivery CC1 / CC2 line for this type of testing.

Test Alt Mode specifications

In addition to the USB Type-C specification, developers must verify the test specifications for the specific alternate protocol, such as DisplayPort or Thunderbolt. For Alt Mode, there are specific areas, such as initialization and control, where testing can be especially challenging because various states of initialization, transmission, power level, and other dynamic parameters require testing under many different scenarios. For example, the DisplayPort specification includes test requirements for various configurations of patterns, test points, levels, and pre-emphasis.

Test Alt Mode cable assemblies

Several challenges are specific to integrating DisplayPort over USB Type-C into your products while ensuring interoperability and achieving test compliance. The Video Electronics Standards Association (VESA) added a new signaling rate in the DisplayPort 2.1 specification, which increased the maximum bit rate to 20 Gb/s per lane. This data rate increase can result in a higher impact of loss, reflection, and crosstalk in signal measurements. Developers must take a more rigorous approach to remove fixtures and matched cable effects to ensure that the measurement is not affected by the test environment (such as test fixtures).

To achieve successful USB Type-C and Alt Mode test results in a timely manner, engineers will need the help of specialized instruments, software, and solutions.

Keysight Solutions

Combining USB and Alt Mode capabilities in the USB Type-C connector has increased the number of verification and conformance tests needed. Test development can be overwhelming for engineers not equipped with the instruments, fixtures, and software needed for Type-C devices, especially as the standards continue to evolve. Using products and solutions specifically designed for these challenging tasks can save time and money while ensuring reliable results.

Verification and test of DisplayPort transmissions with a USB Type-C connector

The Keysight solution for testing and verification of DisplayPort transmissions uses a reference sync, N7015A USB-C fixture, and N7018A USB-C controller. The configuration enables communication to the device first via DisplayPort protocol and then it converts to Type-C. The device under test (DUT) can be controlled by setting the bit rates, level pre-emphasis, and more. The test includes setting the AUX channel control for all the various DisplayPort modes and conditions.

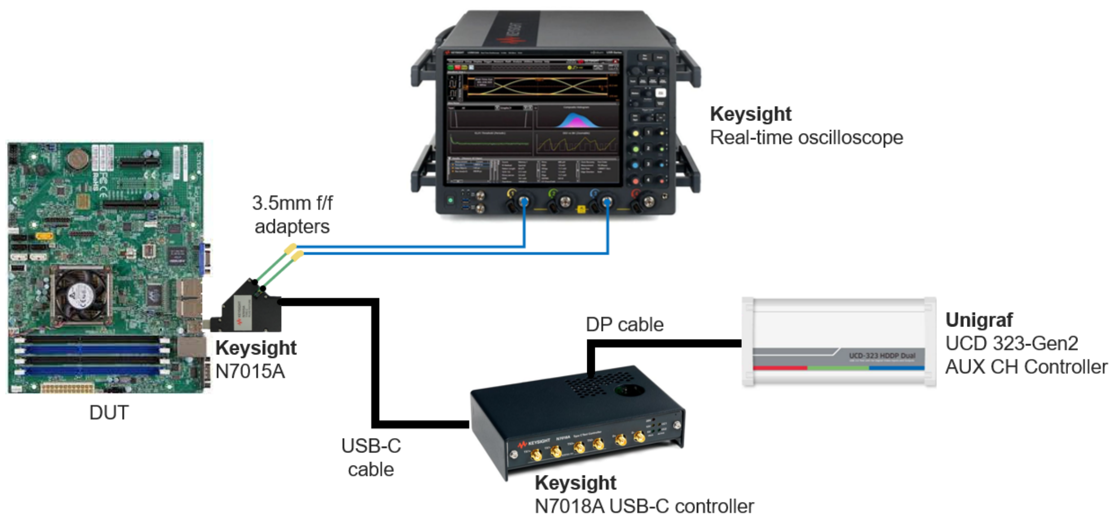

Figure 3. Keysight solution for testing Alt Mode DisplayPort transmissions.

Transmitter test solution

Keysight's DisplayPort 2.1 UHBR Tx verification and test solution includes a UXR-Series Infiniium real-time oscilloscope, D9042DPPC DisplayPort UHBR compliance test software, and N7015A/N7018A TPA fixtures. The solution can perform mathematical processing on the device's transmitted signal, can de-embed the fixture, and embed the cable. It enables continuous time linear equalization (CTLE) according to the desired specification and applies a decision feedback equalizer (DFE) to the highest bit rate. This solution supports acquiring DisplayPort measurements required for various patterns, test points, levels, and pre-emphasis configurations. The flexible software enables developers to change parameter values in debug mode.

Once the test is defined, it can cycle through the various scenarios automatically. Figure 4 shows the test flow for transmitter testing: the oscilloscope acquires data from the DP DUT, then performs processing such as fixture de-embedding, cable modeling, and application of continuous time linear equalization (CTLE) and decision feedback equalization (DFE) filters, then finally performs eye diagram, jitter, level, and spread spectrum clocking (SSC) measurements.

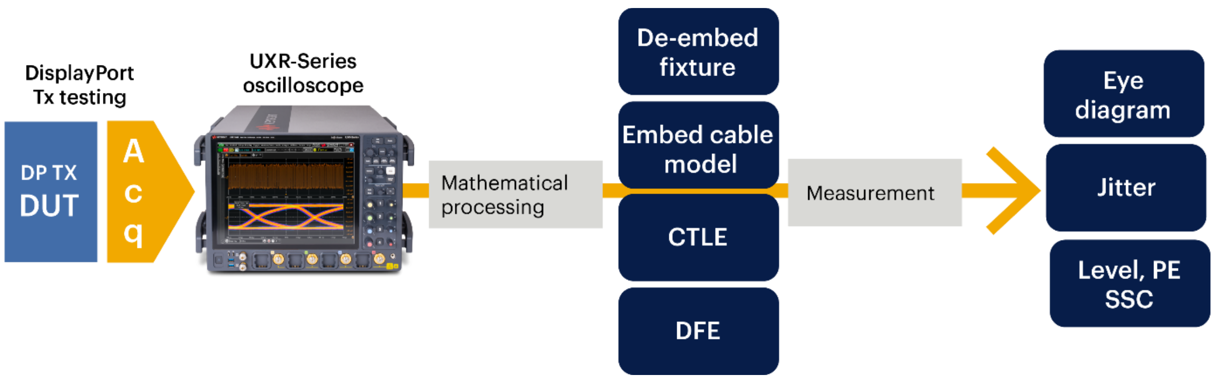

Figure 4. Test flow for DisplayPort transmitter testing using a UXR-Series oscilloscope

Keysight recommends using an Infiniium UXR-Series oscilloscope with at least 21 GHz bandwidth for transmitter testing. The oscilloscope requires the D9120ASIA and D9120JITA jitter, equalization, and de-embedding software packages for performing eye diagram and jitter measurements, as well as D9042DPPC DisplayPort UHBR compliance and validation test software. The D9042DPPC guides the user sequentially through the tasks, ensuring minimal setup error, executes the tests specified by the DisplayPort 2.1 compliance test specification, and conveys the test information through a convenient software-generated report.

Two Type-C test fixtures, the N7015A and N7018A low-speed, are required for test point adapters. The N7015A Type-C high-speed test fixture offers the best signal integrity, enabling signal verification and debug of USB 3.2 10 Gbps, DisplayPort 2.1, and Thunderbolt 3 to support the Type-C connector. The fixture enables signal accessibility and probing to the device and host (upstream and downstream) ports. This is useful for access to all four Tx / Rx pairs, as well as the SBU signals for Alt Mode.

The N7018A Type-C low-speed signal access and control fixture manages power and control lines from the N7015A to support termination requirements, test configuration, and connection to a power delivery controller. This USB-C controller is especially helpful for debugging the power delivery protocol, offering signal access and characterization.

The N7018A connects to the N7015A Type-C high-speed test fixture, providing access to USB 3.2 signals such as CC1, CC2, VBUS, SBU1, SBU2, and ground for system control and diagnosis. It can simultaneously flip the connection electronically — it changes the active USB 3.2 high-speed port — and break out the VBUS signal for driving with a power controller or external supply. The N7018A can also load the VConn pin to simulate a system environment.

Receiver test solution

The Keysight test solution for DisplayPort receiver testing includes the Keysight M8020A high-performance bit error ratio tester (BERT) for level control, jitter addition, crosstalk addition, and calibration. The N5991DP2A automated compliance and device characterization test software for DisplayPort 2.0 testing runs on the BERT. The software includes a test sequencer and required instrument controls.

Keysight's partner, BitifEye Digital Test Solutions, specializes in test automation and provides customizations and integrated solutions based on the N5991A Rx compliance software and the Keysight instrument portfolio.

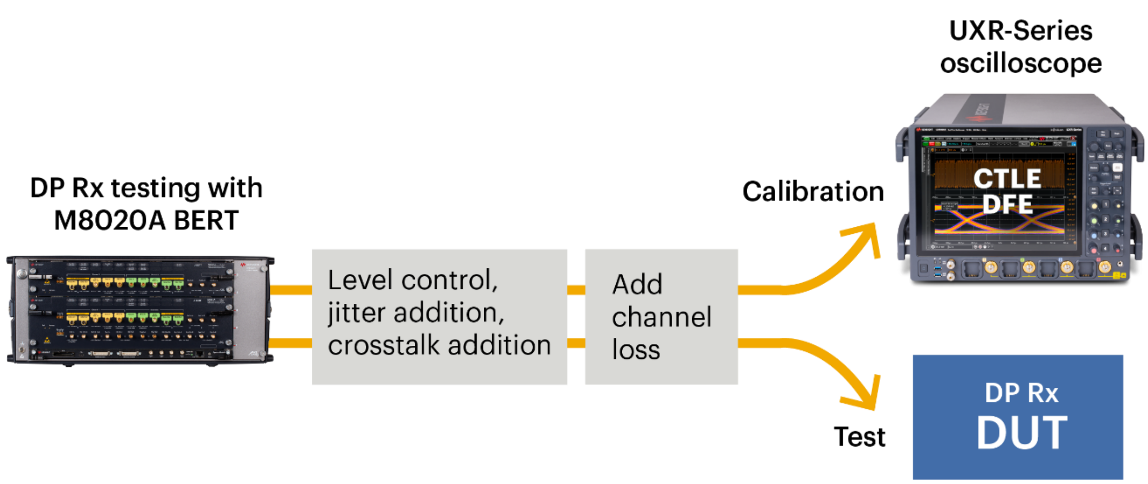

Figure 5. Test flow for DisplayPort receiver testing using UXR-Series oscilloscope

USB Type-C cable assembly measurements solution

Compared to the previous USB 3.2 Type-C compliance test specification (CTS), the CTS for USB4 Type-C is much more complex. The increased bit rates to support USB4 Gen 4 protocols introduce additional signal integrity challenges and require more stringent integrated test parameters corresponding to the incidental / reflective behaviors over a wide frequency range.

The USB-IF introduced a new test called channel operating margin (COM) to qualify USB4 Gen 3 and USB4 Gen 4 cables. COM is a figure of merit to measure the channel's electrical quality; it is essentially the channel signal-to-noise ratio (SNR). COM test compilation includes the consideration of noise sources from inter-symbol interference (ISI), crosstalk, transmitter jitter, and receiver equalization.

Test fixtures are required to connect the test equipment to the cable assembly. At the 20 Gb/s data rate, it is essential to remove the effects of the fixture to ensure sufficient yield; the 2x thru de-embedding method is recommended. For 2x thru de-embedding, full calibration is performed with an electronic calibration (Ecal) unit to establish the calibration reference plane at the end of the test cables. Then, the S-parameters of the fixture traces are de-embedded to extend the reference plane to the edge of the USB connectors, effectively removing the effects of the fixture from the measurement. The key to the de-embedding method is the quality of the S-parameters of the fixture traces. The automatic fixture removal (AFR) feature is recommended to obtain these S-parameters.

AFR is a rigorous approach to removing fixture effects to measure the true performance of the device. Learn more about de-embedding in the ABCs of De-embedding application note and about USB Type-C cable and connector testing in Interoperability and Compliance of USB Type-C Cables and Connectors.

S94USBCB: USB Type-C Interconnects Compliance Test Software

Conclusion

The compliance tests for USB Type-C alternate mode demand multiple test regimens for each device. Using the best instruments, fixtures, and software available can help you address the growing number of tests while making test setup easier, providing accurate signal generation and measurements, and automating testing, when possible, for repeatable results and reduced overall test times.

Keysight's Type-C solution set — software, instruments, and fixtures — is ready for complete testing of the standards converging on the USB Type-C interface. Whether you are focused on design or validation, the Keysight solution will ensure you move swiftly from debug to characterization to compliance and finally, to completion.