Keysight Technologies
How to Ensure Interoperability and Compliance of USB Type-C™ Cables and Connectors
Keysight and Type-C: Create a faster path to done

Application Note
Overview

USB Type-C™ is a breakthrough standard designed to meet the demand for technology that supports new, ever smaller and thinner computers and devices, higher-speed data, and more power and flexibility. Key USB Type-C areas of focus include the connection between devices, managing power, and ensuring valid data transmissions. The USB Type-C connection provides:

- Dynamic power and transmission of USB 2.0 with other protocols
- The ability to be a key interface for many new and future devices
- Backward compatibility
- Ease-of-use as a result of reversibility

Design and test engineers face a number of challenges as they work to integrate USB Type-C into their products, while ensuring interoperability and achieving test compliance. Because USB Type-C compliance test standards have increased and become more complex due to higher data transmission speeds, more power, and additional functionality, successful testing requires highly accurate and standard-compliant test instruments, software, and fixtures.

Type-C Cable and Connectors

Several variations of USB cables are used to connect and power devices: Type-A, -B, Micro, Mini and others.

Compared with these existing types of USB cables, Type-C cables offer the distinct usability advantage of being both symmetrical and reversible. Anyone who uses computers and peripherals knows that USB standard A/B connectors must be plugged in in a single direction, and it may take a few attempts to find the correct orientation. The USB Type-C connector is much easier to plug in because it is symmetrical and can be plugged in in either direction, between any USB Type-C devices.

Design and test engineers face several challenges as they update their device interface from 4-pin USB standard A/B connectors to the 24-pin USB Type-C connector. The new USB Type-C receptacle and cable (also called channel) includes design changes that address issues with standard A/B type connectors/cables and offer more features and capabilities for new Type-C enabled products. Understanding test challenges and solutions can help ensure successful USB Type-C integration and test for devices.

The USB Type-C cable and connector (the channel) provides not only backward USB compatibility, but also increased functionality for power management and data transmission. USB Type-C power delivery provides up to 20 volts, 5 amps and 100 watts for dynamic power and charging of different devices. The transmit/receive (Tx/Rx) pairs can be used for USB or “guest protocols” such as DisplayPort, MHL, or Thunderbolt data transfer, making it possible to transfer high-speed data, video and audio signals in addition to USB. Type-C data transfer rates are up to 20 Gbps (Thunderbolt), with the ability to achieve 40 Gbps in the future. These new capabilities create a greater challenge for design and test engineers who are working to ensure the interoperability of their USB channel and devices by performing USB-IF standard conformance tests.
Pin functionality overview

Two pins (CC1, CC2), 1 pin repurposed for Vconn

These pins determine cable configuration and include cable orientation detection. The USB Type-C connector maintains a host-to-device logical relationship, even though it is reversible, using a single-wire orientation detection. There is only one CC signal wire present in the Type-C cable. When the cable is plugged into the receptacle, the wire connects from CC of the receptacle to either CC1 or CC2 on the other end, which determines the cable orientation. The other CC pin is repurposed as Vconn (a 5V power rail) for powering the power circuit in active cables, eliminating the need to use power from the Vbus.

Two differential pairs (D+/D-)

These USB 2.0 data bus pins are dedicated and ensure that USB 2.0 backward compatibility is always available.

Four power/ground pairs (Vbus, Gnd)

The power delivery circuit manages multiple peripheral devices and provides power for devices to operate at their set power levels. Devices are able to request the power they need, and get more power when required for a specific application.

Four transmit/receive pairs (TX1+/-, RX1+/-, TX2+/-, RX2+/-)

These pins can be used for high-speed data bus or Alternate (ALT) mode. The four sets of transmit and receive (Tx/Rx) pairs, allow for one, two or all four channels to be used for data transmissions at any time. The Type-C connection makes it possible for two different protocols to actively transmit and receive simultaneously, or double the Tx/Rx speed for a single protocol in future USB implementations.

Two secondary bus pins (SBU1, SBU2)

The secondary bus or “sideband” signals are not currently specified for Type-C connections. However, they may be used for Alternate mode transmissions or other future scalability.

Previously, the USB connection consisted of power and two data lines, but the USB Type-C channel is able to dynamically change power levels and data signals. When the initial end-to-end USB Type-C connection is made, cable orientation is resolved through the use of CC1/CC2 pins, and devices acknowledge the connection and establish host/device roles. Then, the power delivery circuit begins to manage power to each connected device through Vbus and Gnd connections. Individual devices determine which of the Tx/Rx pins (and SBU1/2 pins for alternate protocols) are used. The Tx/Rx pins may be used for USB or other protocols, and pins can be combined in parallel for faster data transfers. Channel power and signal levels are managed by the power delivery circuit and can change while a device is connected for charging or new transmissions.

Consumers using USB Type-C enabled products will find them to be much more capable and simple to use. Engineers, however, have a lot more complexity to manage during test, especially when considering the many different scenarios of functionality the channel will need to be tested in.
USB Type-C cable and connector test challenges

USB Type-C cable and connector test challenges result from the large number of specifications and backward compatibility requirements. However, meeting these tough specifications is critical because it ensures successful interoperability of USB products.

According to the USB-IF, previous versions of USB specification signals (USB 2.0 and 3.0) must be supported by Type-C. Along with this required backward compatibility, the USB-IF has defined two USB Type-C cables, both with Type-C plugs at each end:
- The USB 3.1 Type-C cable can be either 10 Gbps Gen2, or 5 Gbps Gen1 (longer cable, ~2 meters)
- USB 2.0 Type-C to legacy host (typically for mobile charging)

Rather than specified cable lengths for electrical compliance channels, USB 3.1 and Type-C have specified channel loss, which plays a key role in ensuring interoperability of USB hosts and devices. An example would be a two meter cable which is required to have no more than 7 dB of insertion loss. With a 20 dB SuperSpeed Gen 1 limit, only 13 dB are remaining to split between the host and device.

USB Type-C channel specifications, including symmetrical connectors, high-speed data, high power, multiple data transmission types, and backward compatibility, result in a large number of configurations that need to be tested to verify USB channel conformance. Performance of the channel in various configurations is also affected by loss, as mentioned above, as well as reflection, and cross-talk. More rigorous methods than what have been used in the past are needed to remove test fixture effects, to manage additional effects on channel response, and to manage EMI and RFI levels in the USB Type-C channel during USB compliance testing.

Removing test fixture effects

Accurate electrical characterization of the Type-C interconnects over a wide range of frequencies is critical for high-speed bus design. With the increased data rate of 10 Gbps, characterization becomes more challenging. Electrical characterization of high-speed interconnects is usually done in the frequency domain using a vector network analyzer (VNA). A fixture is used to connect from the device under test (DUT) to the VNA. A complete removal of the test fixture is crucial to prevent fixture artifacts from affecting test results, especially at higher frequencies. Fixture removal is achieved by calibration or de-embedding processes and the quality of the instrumentation and process used is reflected in the resulting measurement accuracy.
Effects on channel response

Channel response is affected by loss, reflection, cross-talk, and mode conversion. Traditionally, interconnections have been characterized by measuring parametric characteristics, such as impedance and skew for time domain, and insertion loss and return loss in the frequency domain, and by testing to specific parameter limits. The parametric specification has conservatively set limits, requiring interoperability for cables that marginally pass the parametric test items. This test method no longer works because it doesn’t allow for trade-offs between the parameter performances. For example, a channel with less loss could tolerate more cross-talk or reflection, and vice versa. A new test methodology and improvements in the pass/fail judgement method are required for Type-C channels. Type-C channels are characterized using the eye diagram which allows a direct observation of eye characteristics at the end of the link. This measurement is called “stressed eye” diagram analysis.

For stressed eye diagram analysis, the expected worst case performance signal of the transmitter is applied as the “stressed” signal to the interconnect, and the output of the interconnect is evaluated using an eye diagram. If the interconnect correctly transmits a stressed signal with eye characteristics equal to or better than what is specified at the receiver input, then it should operate with the signal of any compliant transmitter. Engineers using the eye diagram apply various forms of signal conditioning, emphasis, and/or equalization, while pass/fail testing of the interconnect is performed.

Figure 4. Channel response is affected by many features in the channel (loss, reflection, crosstalk, mode conversion) and requires a new measurement methodology involving a shift from traditional parametric to stressed eye testing (channel metrics/margin).
Managing EMI and RFI levels from the cable assembly

A newer Type-C receptacle design provides more grounding and better overall shielding to prevent RF leakage and has reduced USB 3.1 RFI problems. New specification standards were also added for Type-C to manage cable radiation by requiring cable shielding effectiveness measurements.

The cable shielding effectiveness test measures the RF interference (RFI) levels from the cable assembly. To perform the measurement, the cable assembly is installed in the cable shielding effectiveness test fixture, which is currently under development by the USB-IF. This test fixture has five SMA connectors: two each for the Tx and Rx pairs, and one to connect to the cable shield. The coupling factors from differential mode to cable shield (Ssd12) and common mode to cable shield (Ssc12) are measured for the Tx and Rx signal pair respectively.

Cable/connector measurement solutions

Keysight solution for test fixture effects

Traditional cable/connector compliance tests have used a vector network analyzer (VNA) for the frequency domain analysis, and a TDR (time domain reflectometry) oscilloscope for time domain analysis. A new recommended solution is to use a Keysight ENA series network analyzer with enhanced time domain analysis (option TDR) for a one-box solution that measures all of the compliance parameters. A microwave electronic calibration (ECal) module, N4433A, which is controlled from the ENA USB interface, is used for ENA calibration and to remove the effects of the test setup.

– Keysight provides Method of Implementation (MOI) step-by-step procedures for specified parameter measurement upon the release of USB-IF compliance documentation. The USB Type-C Cable Connector Assembly MOI can be found at: http://www.keysight.com/find/ena-tdr_usbtype-c-cabcon

In addition to USB, the ENA Option TDR is certified for measurement on a variety of high speed serial standards. The procedures are available for a free download at www.keysight.com/find/ena-tdr_compliance.
Typical configuration

- ENA Mainframe
  - E5071C-4K5: 4-port, 300 kHz to 20 GHz. This option is recommended, since the Type-C cable/connector requires measurements up to 15 GHz.
  - Enhanced time domain analysis option (E5071C-TDR)
  - ECal module (N4433A)

Note: This list includes the major equipment required. Please contact a sales representative for configuration details.

The Keysight E5071C ENA Series network analyzer is an ideal solution for manufacturing and R&D engineers evaluating RF components and circuits for frequency ranges up to 20 GHz.

The N4433A Microwave electronic calibration module (ECal), 300 kHz to 20 GHz, 3.5 mm, 4-port can be combined with a vector network analyzer for fast, accurate, full three- or four-port calibration. In addition, many of the test centers for high speed serial compliance testing have already adopted ENA Option TDR.

The Keysight N1930B Physical Layer Test System software (PLTS 2016), automatic fixture removal (AFR) works with Keysight PNA and ENA network analyzers (including the new PXI VNA architecture) to provide a powerful signal integrity tool for today’s high-speed digital designers. PLTS is the signal integrity industry solution for measurement and analysis of physical layer devices. Wizards help users to easily calibrate and measure multiport devices. Once measured, PLTS provides display, analysis, reformatting and conversion tools as well as import/export capabilities.

Conclusion

The new USB Type-C specification introduces many new challenges in cable assembly test. The ability to address signal integrity issues that can negatively affect system performance as bit rates increase, while accelerating interconnect testing and characterization, are critical. Perform high-speed interconnect analysis, including impedance, S-parameters and eye diagrams, with the one-box ENA Option TDR solution.

Keysight’s Type-C solution set—software, instruments and fixtures—is ready for complete testing of the standards converging on this universal interface. Whether you’re focused on design or validation, our solution will accelerate you from debug to characterization to compliance to done.

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