Keysight Technologies
How to Address USB Type-C™ Transmitter and Receiver Test Challenges
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.

USB Type-C Transmitter/Receiver Requirements

USB has changed from a simple 4-pin connection for power and data to a symmetrical, reversible, highly functional 24-pin connection. The USB Type-C connection provides more design flexibility for device transmit/receive and includes 4 sets of transmit and receive (Tx/Rx) pairs. This allows for one, two or all four channels to be used for data transfer at any time. Two different protocols are now able to actively transmit or receive simultaneously, or a single protocol can transfer at double the Tx/Rx speed, up to 20 G and even faster data rates in the future. Enhanced power delivery provides up to 20 volts, 5 amps and 100 watts for bi-directional device charging. These combined Type-C features and enhancements create a much more challenging USB Tx/Rx conformance test criteria.

Understanding the USB Type-C and USB 3.1 transmitter and receiver test challenges can help to ensure successful USB Type-C integration and test for devices.
Test fixtures and cabling can become significant sources of signal loss during test, especially with increased data rates, and can adversely affect device performance measurements. For accurate signal characterization in high-speed compliance tests, de-embedding techniques are needed to remove the effect of test fixtures on measurements in order to characterize true device performance. Using test fixtures with good signal integrity minimizes channel loss and is important when measuring S-parameters for fixture characterization prior to de-embedding.

Tx and Rx compliance testing requires running compliance test patterns. These various signal patterns are generated during compliance tests, while measurements are made in a tool known as SigTest. For additional SigTest information please see [http://www.usb.org/developers/tools/](http://www.usb.org/developers/tools/).

**USB 3.1 and Type-C Transmitter Test Challenges**

Each transmitter compliance test presents individual challenges for USB 3.1 and Type-C. The greatest overall challenge is the increased number of compliance regimens that must be performed due to an increased number of channels, flexible configurability, and the reversible connector. USB-IF compliance testing will require a number of loading and charging conditions which increases the number of tests engineers must configure and execute for each device. These tests include:

- USB 3.1 Gen 1 tests of transmitted eye
- Low frequency periodic signaling (LFPS) timing
- Transmitted spread spectrum clock (SSC) profile for transmissions
- New USB 3.1 Gen 2 tests:
  - SuperSpeedPlus Capability Declaration (SCD)
  - Low frequency periodic signaling (LFPS) based pulse width modulation messaging (LBPM)
  - De-emphasis
  - Pre-shoot

**Transmitted eye test**

The transmitted eye test requires that the resulting signal meet eye height and width, deterministic jitter, and random jitter specifications. The device under test is put into compliance mode where it transmits compliance patterns. The patterns are captured by a high-speed oscilloscope, and eye specifications are measured.

**Low frequency periodic signaling (LFPS)**

LFPS is a series of pulses separated by constant time intervals. The LFPS tests ensure signal quality and the correct characteristics to negotiate and train to the right data rate. The test includes the addition of a side-band communication sent on the normal SuperSpeed data lines at a lower frequency (10-50 MHz instead of 5 Gbps). The side-band helps to manage signal initiation and low power management on the bus on a link between two ports.
Spread spectrum clocking (SSC) modulation signal

The SSC modulation signal is a required test for USB 3.1 Gen 1 and Gen 2 in regard to electromagnetic interference (EMI) and ensures the device is able to transmit an accurate profile that a receiver can handle. USB devices initialize and immediately go into SSC mode. Managing the effect of EMI is often the greatest challenge for transmitter test because it can cause a high magnitude peak at the carrier frequency, and harmonics that may exceed specified limits. To prevent this problem, SSC can be used to spread the energy of the frequency spectrum, and stay within test limits. SSC testing presents challenges to the clock and data recovery circuit (CDR) due to the large, low frequency difference between the local clock and incoming data. USB specifications help limit the impact of SSC on the CDR. Often times it is necessary to analyze the effects of SSC to resolve system interoperability issues.

SuperSpeed Capability Declaration (SCD)

SCD is part of the link training status state machine (LTSSM) sequencing. It is also the core of the USB 3.1 Gen 2 link layer and defines link connectivity and link power management states and transitions. Signal quality for these protocols and timing is very important. The DUT must generate the SCD1 and SCD2 signals, while the signal quality measurements (period, rise and fall time, voltage, etc.) are verified. These signals ensure the device is able to negotiate to the correct link (Gen1 or Gen2).

LFPS Based Pulse Width Modulation Messaging (LBPM)

LBPM is a protocol used by link partners to negotiate up to Gen 2. Signal quality tests ensure a device is able to negotiate up to USB 3.1 Gen 2.

De-emphasis (attenuation) and pre-shoot

De-emphasis (attenuation) and pre-shoot are types of equalization used to address the effects of the lossy channel. The fixture (including the USB reference channel and cable) between the pattern generator (transmitter) and the analyzer (receiver) causes a frequency-dependent loss resulting in inter-symbol interference (ISI) or eye closure. To address the loss, transmitter de-emphasis is used to boost the high frequency components of the signal, which opens the eye at the receiver. USB-IF requires signal quality measurements to ensure the transmitted signals meet specifications, and when the generated signals go through the high loss cable they arrive at the receiver in the best possible condition.
During transmit test, a high-speed oscilloscope is used to measure signal quality of each of the specified compliance waveform patterns as they are transmitted. An oscilloscope is used to do jitter decomposition, and random jitter ($R_j$), deterministic jitter ($D_j$), and total jitter ($T_j$) analysis to determine the root cause of jitter for the jitter budget.

Mask testing a transmitter quickly defines key regions where signals are not allowed. If signals appear in the defined region, the device fails. Keeping transmitted signals within the limits of eye height/mask is even more difficult to achieve for USB 3.1 and Type-C, making the quality of mask measurements critical. For $E^6$, the eye height target after equalization is 70 mV, so for $E^{12}$, the eye height target is 30 mV. The eye width at $E^6$ is 47 ps after equalization and is very difficult to achieve.

For compliance, an oscilloscope with a bandwidth of 25 GHz (30 GHz for Thunderbolt) is needed. More bandwidth is needed if you measure closer to the Tx silicon. Measurements for eye height, eye width, signal amplitudes, jitter analysis, average data rate, and rise/fall times are made for each signal. Also, because the Type-C connection is reversible, both sets of Tx/Rx channels need to be tested. Testing must be performed for all protocols that will be transmitted.

### USB 3.1 and Type-C Receiver Test Challenges

A difficulty of testing the Tx/Rx link with a verified Tx signal is the lack of visibility at the end of the transmitted link within the receiver. Even though a transmitted signal looks correct, the eye could be closed within the receiver. The stressed eye calibration test requires that compliant fixtures and cables have various types of jitter and crosstalk stresses applied. Test instruments are used for pattern generation with the ability to add signal stresses and perform signal analysis, including jitter and eye measurements.

Once the stressed eye has been calibrated, the receiver can be tested. Compliance tests for the USB 3.1 receiver use the worst case signal condition (stressed eye calibration) as an input, then apply additional sinusoidal jitter ($S_j$) of increasing frequency. Tests are performed at multiple frequencies to ensure proper function of the receiver. Many of the compliance patterns generated are also used for calibration during Rx testing. The receiver tests help characterize the performance of the USB device under varying conditions of amplitude and jitter. USB 3.1 jitter testing requires bit error ratio (BER) testing, which is a form of jitter tolerance test. The receiver is tested with stressed eye varied by a series of $S_j$ frequencies and amplitudes, while the error detector monitors the receiver for mistakes or bit errors and calculates the BER. The test configuration requires a pattern generator that can apply different conditions, including the ability to generate true random jitter for the target BER.

Dealing with asynchronous testing on the BER error detector can also be a test challenge. The Tx/Rx system tests its ability to pass bits without error. However, encoding for USB 3.1 has become more complicated with increased bandwidth, which creates a much more complex protocol and difficult implementation. Typically, the transmitter and receiver are on slightly different clock frequencies; the recovered clock of the received data stream may be slightly different than the clock frequency of the transmitter. The difference causes a problem for the device when the receiver is in loopback mode. The bits may be received faster or slower than they can be transmitted back out. To address the frequency mismatch, clock compensation symbols are used and either deleted or inserted into the data stream as it travels from the receiver back through the transmitter. Instruments in the test configuration must be able to handle the non-deterministic number of clock compensation symbols in the incoming data stream, called asynchronous BER testing. The analyzer must be able to filter 128-bit/132-bit coded skip-ordered sets with variable length during error counting.
Conformance testing determines the receiver’s ability to properly detect transmitted digital signal content, even for worst-case impaired input signals. To emulate a system's transmitted worst case data signal, including impairments according to the compliance test specification (CTS), the best instrument is a BER tester’s pattern generator (BERT PG). While emulating the receiver in test mode, and receiving the calibrated test signal, the BERT is able to detect the digital content and monitor the performance according to the target BER. A BERT contains both pattern generator and signal analysis capabilities, as well as calibrated stress conditions such as SSC, SJ, RJ, de-emphasis, and ISI, and should be the test instrument selected for receiver testing.

Transmitter Test Solutions

For Tx compliance test of USB 3.1, DisplayPort 1.3, Thunderbolt 3 and MHL, the N7015A and N7016A Type-C test fixtures, for use with Keysight Infiniium oscilloscopes, are recommended. This solution offers the best signal integrity with 20 GHz bandwidth (at -3 dB), and is de-embeddable up to 30 GHz. It includes a Type-C plug interface fixture which handles connector “flip” and provides test point and probing access for transmitter and power delivery measurements.

- **N7015A Type-C high-speed test fixture** provides up to 30 GHz of de-embeddable bandwidth, enabling signal verification and debug of USB 3.1 Gen 2, DisplayPort 1.3, and Thunderbolt 3 to support the Type-C connector. The fixture breaks out 4 lanes of high speed signal for signal measurement or injection and enables signal accessibility and probing to the USB 3.1 device, host and (upstream and downstream) ports.

- **N7016A Type-C low-speed signal access and control fixture** manages power and control lines from the N7015A Type-C high-speed test fixture to support termination requirements, test configuration, and connection to a power delivery controller. The N7016A provides access to USB 3.1 signals such as CC1, CC2, VBUS and ground for system control and diagnosis. It can simultaneously flip the connection electronically (change the active USB 3.1 high-speed port) and break out VBUS for driving with a power controller or external supply. It can also load VConn to simulate a system environment.

- **U7243B USB transmitter compliance test software application** and Keysight’s Infiniium oscilloscopes can be used to perform transmitter compliance and validation testing as defined by the USB 3.1 specification. The Infiniium V-Series oscilloscopes provide the lowest noise floor in the industry, which is especially important with the high serial speeds of USB 3.1 and the decreased margin that these speeds impose.

Receiver Test Solutions

The M8020A J-BERT high performance 16 Gb/s BERT has everything you need built into the equipment (de-emphasis, pattern capabilities, continuous-time linear equalization (CTLE), decision feedback equalization (DFE), the capability to create the various pattern structures, and re-sequencing). The Keysight USB 3.1 receiver test solution provides accurate and repeatable test results enabled by the M8020A J-BERT’s built-in and calibrated jitter sources (random jitter, period jitter, SSC), precise emulation of pre- and post-cursor de-emphasis, and inter-symbol interference (ISI) traces.
Key capabilities:

- Analysis of coded and re-timed data
- Supports symbol rate (rather than bit rate) to de-code structures 128b/130b, 8b/10b and hardware scrambling capabilities
- Error counting accomplished by real-time filtering of the USB 3.1 specific 128b/132b coded skip-ordered set (that can vary in length from the pattern stream)
- Generates calibrated stress conditions for Rx test (SSC, SJ, RJ, De-emphasis, ISI)
- Emulates LFPS 3-level signals with built-in electrical idle for loopback training and via channel
- Integrated link training, Tx Eq, noise impairment, variable ISI, receiver equalizer/eye opener
- Ability to create common mode signals from the amplifier reducing complexity
- Built-in clock recovery

Addressing receiver test challenges:

- Receiver stress test calibration: Use the oscilloscope’s built-in CDR and equalizer emulation for eye height and eye width measurement
- Dealing with asynchronous testing on the BERT error detector: SKP and SKP OS filtering options for M8020A J-BERT OS2 enable error counting for USB 3.x
- Getting a DUT into a respective test mode: Utilize the M8020’s J-BERT powerful pattern sequencer in combination with the BitifEye link training suite

Accurate and repeatable receiver characterization with the M8020A J-BERT pattern generators allows you to emulate link training sequences to bring the host or device into loopback mode. The M8020A enables emulation of stress conditions, even beyond margins without external sources. It has built-in, calibrated sources for SJ, RJ, and ISI traces to emulate channel effects. SSC can be emulated, and adjustable de-emphasis is available.

The M8020A simplifies receiver test setup and provides analysis for re-timed and coded data from the USB device. The M8020A J-BERT analysis option filters SKIP/ALIGN symbols without dead times and automatically handles running disparity flips, and displays error ratio as symbol error ratio, or calculated BER.

Conclusion

The USB 3.1 and Type-C specifications introduce many new USB transmitter and receiver test challenges. The ability to quickly and accurately measure key aspects of the transmitted eye, LFPS and LBPM timing, transmitted SSC profile, SCD signals, and to perform de-emphasis and pre-shoot will be critical for successful transmitter test. Flexible signal generation and bit error detection are key for receiver test validation.

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.

Download your next insight

Keysight software is downloadable expertise. From first simulation through first customer shipment, we deliver the tools your team needs to accelerate from data to information to actionable insight.

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