Universal Serial Bus 4 (USB Type-C) Captive Device Electrical Compliance Test Specification

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1.01	08/03/2021	Updating TX and RX Freq variation training tests and some typo. TX RL (diff + common). Updating figures.
1.02	06/08/2022	Updating TP3 Gen2 EW/EH

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Acronyms

Acronym	Definition
BER	Bit Error Rate
BERT	Bit Error Rate Tester
BW	Band Width
CDR	Clock Data Recovery
DUT	Device Under Testing
NVM	Non Volatile Memory
PJ	Periodic Jitter
SSC	Spread Spectrum Clock
TJ	Total Jitter
TP3	Test Point 3
UI	Unit Interval
UJ	Uncorrelated Jitter
UDJ	Uncorrelated Deterministic Jitter
RJ	Random Jitter
ISI	Inter Symbol Interference
DDJ	Data dependent Jitter
PPM	Parts Per Million
PRBS	Pseudo Random Bit Sequence

1 Introduction

This document contains the specification of procedures, tools and criteria for testing compliance of Captive Device according to the Universal Serial Bus 4 (USB Type-C) Version 1.0.
This CTS is detailing the post-processing that should be done over the saved waveform from the scope. Since USB4 SigTest is published all post-processing for Captive Device Transmitter testing and Receiver calibration must be done using the published USB4 SigTest.
This CTS is aligned to USB4 SigTest rev0.6 and USB4 SigTest User Manual rev0.6
All details how the use the SigTest is written over the USB4 SigTest User Manual rev0.6

2 Test Equipment

2.1 Overview

All equipment used for testing shall comply with the requirement lists specified below.

This includes the primary equipment that is used in the USB4 authorized test centers and should also, if possible, be used by the end user for self-testing.

Other configurations and equipment may be used for self-testing as long as that equipment and the processes meet all of the stated and implied requirements and permit an equivalent level of testing.

2.2 Test Equipment Requirements

All test equipment requires calibration to ensure accurate and repeatable results. Equipment shall be calibrated prior to, and if necessary, during the test procedure.

2.2.1 Test Point Access Boards

To gain access to the required signals, a variety of test point access boards are required. Test Point Access boards provide test points for the pins on the USB4 USB Type-C connector and an easy way to control the DUT.

Recommended Test Equipment:

1. Wilder USB4 Plug and receptacle Test fixtures.
2. Wilder USB4 Micro-Controller Test Module with USB cable.
3. Control PC \ Scope running the latest USB4 SW Electrical Test Tool (ETT).

2.2.2 Real Time Scopes

Required Test Equipment Capabilities:

- DC to 21±1GHz, -3db bandwidth or greater
- 80G sample/sec Sampling rate or greater, sampling 2 channels simultaneously
- Sample memory: 2 channels at 50M samples per channel or greater
- 1st and 2nd order CDR capability
- Equalization and DFE
- Jitter measurement
- Embedding/de-embedding capability
- High impedance probe

2.2.3 Pattern Generator

Generate USB4 signal with a variety of patterns, jitter injection capability.

Required Test Equipment Capabilities:

- Data rates ≥ 20Gbps
- Data patterns: PRBS15, PRBS31, Square wave
- Differential swing range: 0 – 2Vp-p in 10mV steps
- Rise Time ≥ 10 ps (20%-80%)
- Intrinsic jitter ≤ 400 fS RMS
- Random Jitter profile no smaller than 500MHz
- Equalization
- Ability to create RX clk switch SSC profile as requested in the USB4 base spec
- SSC spread deviation from 0.03% down to -0.53%. Note – for Interoperability with Thunderbolt™ 3 (TBT3) Systems the SSC spread deviation shall be from 0.04% down to -0.54%.
- Injection of 1 SJ sources

2.2.4 Network Analyzer

Required Test Equipment Capabilities:

- 2 ports used simultaneously
- At least 1MHz – 20GHz bandwidth
- Dynamic range > 50db
- Time domain option
- The de-embedding files (s4P) should be up to 20GHz.

2.2.5 Signal Generator

Required Test Equipment Capabilities:

- Frequency range of at least 10- 400MHz
- Output power of ±15dBm

2.2.6 Accessories

2.2.6.1 Low Insertion Loss Phase Matched Cables:

Required Test Equipment Capabilities for 1m RF cable:

- Phase matched max of±5º @ 40 GHz
- Max IL in 10GHz < 1.5dB

Note – any length of cable is permitted up to 1m.

2.2.6.2 ISI Channel

Required Test Equipment Capabilities:

Varied insertion loss of 2-10dB @5GHz and @10GHz

2.2.6.3 Pick Off Tee

Required Test Equipment Capabilities:

Pick off tees with bandwidth of at least 40GHz

2.2.6.4 Splitter

Required Test Equipment Capabilities:

Splitter with bandwidth of at least 1GHz

2.2.6.5 DC Block

Required Test Equipment Capabilities:

- DC Blocks with bandwidth of at least 33GHz
- 1 dB Insertion Loss to 40 GHz
- Capacitance of 135nF-265nF (220nF is recommended)

2.2.6.6 USB4 Passive cables

- USB Type-C 0.8m (Gen3 supported) and 2m (Gen2 supported) passive cables as described in the USB4 Specification. The cables should be e-marked.

2.2.6.7 Termination

Required Test Equipment Capabilities:

- Impedance 50 ohm
- Frequency DC to 20 GHz

3 Captive Device Transmitter Testing

- Captive Device transmitter compliance testing is defined at the output of USB Type-C Receptacle fixture referenced to test point TP3 (as the Captive Device may include a Passive Cable at its front-end).
- TP3- Reference measurement point located at USB Type-C receptacle output on the far-end side of passive cable. Used as a reference point for passive installations. All the measurements at this point shall be done while applying reference equalization.
- All measurements should be referenced to the TP3 compliance point.
- Calibration should be applied in cases where direct measurement is not feasible.
- All jitter measurements are referenced to the average frequency.
- As written in the Introduction – all post processing is done using the USB4 SigTest

The following sections provide detailed information on the setup and testing of the USB4 parameters. In the event of a discrepancy, the USB4 Specification prevails.

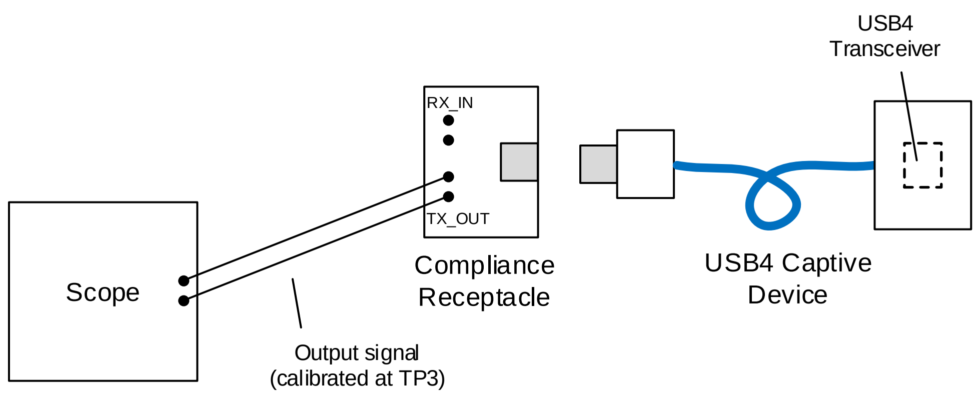


Figure 1. USB4 Captive Device TX Compliance Point Definition

3.1 Transmitter Test Setup

The following figure shows the connections to the DUT and control PC used for Transmitter testing.

Note: Before beginning any test or data acquisition, the Oscilloscope must be warmed, and calibrated. The cables used for measurement should be de-embedded (4 port). For all tests the signal must be vertical tuned to be opened.

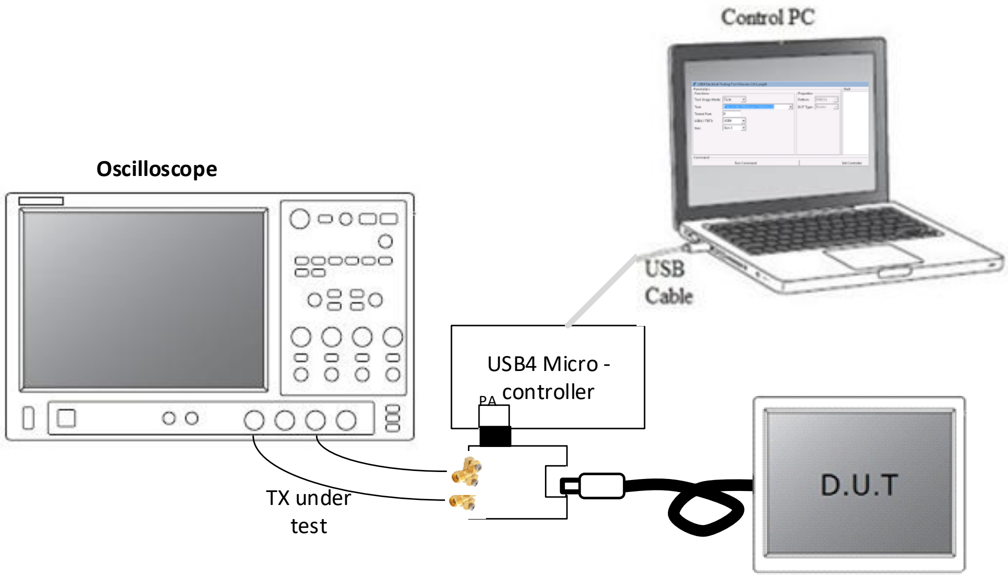


Figure 2. Transmitter Test Setup

3.2 Connecting to the DUT

1. Connect Lane under test TX_P, TX_N to the Oscilloscope.
2. Connect the Low speed signals from the USB4 test Fixture to the USB4 Micro-controller PA directly.
3. The USB4 Micro-controller is connected to control PC via USB cable, running the latest USB4 SW Electrical Test Tool (ETT).
4. Note – the Transmitter Captive Device is tested with the default preset. It is recommended that the default preset will be the one that causing the transmitted signal to be with minimum DDJ. See Appendix C.

3.3 Gen 2 Captive Device Transmitter Compliance

3.3.1 Gen2 Transmitter Equalization

3.3.1.1 Reference

USB4 Specification Table 3-3 and 3-5

Preset Number	Pre-shoot [dB]	De-emphasis [dB]	Informative Filter Coefficients		
			C_{-1}	C_0	C_1
0	0	0	0	1	0
1	0	-1.9	0	0.90	-0.10
2	0	-3.6	0	0.83	-0.17
3	0	-5.0	0	0.78	-0.22
4	0	-8.4	0	0.69	-0.31
5	0.9	0	-0.05	0.95	0
6	1.1	-1.9	-0.05	0.86	-0.09
7	1.4	-3.8	-0.05	0.79	-0.16
8	1.7	-5.8	-0.05	0.73	-0.22
9	2.1	-8.0	-0.05	0.68	-0.27
10	1.7	0	-0.09	0.91	0
11	2.2	-2.2	-0.09	0.82	-0.09
12	2.5	-3.6	-0.09	0.77	-0.14
13	3.4	-6.7	-0.09	0.69	-0.22
14	3.6	0	-0.17	0.83	0
15	1.7	-1.7	-0.05	0.55	-0.05

Transmit Equalization Presets Table

3.3.1.2 Requirement

Transmitter swing 3.5 ± 1dB (for preset 15 only).
Pre-shoot, de-emphasis ± 1dB for the Presets specified in the Transmit Equalization Preset Table above.

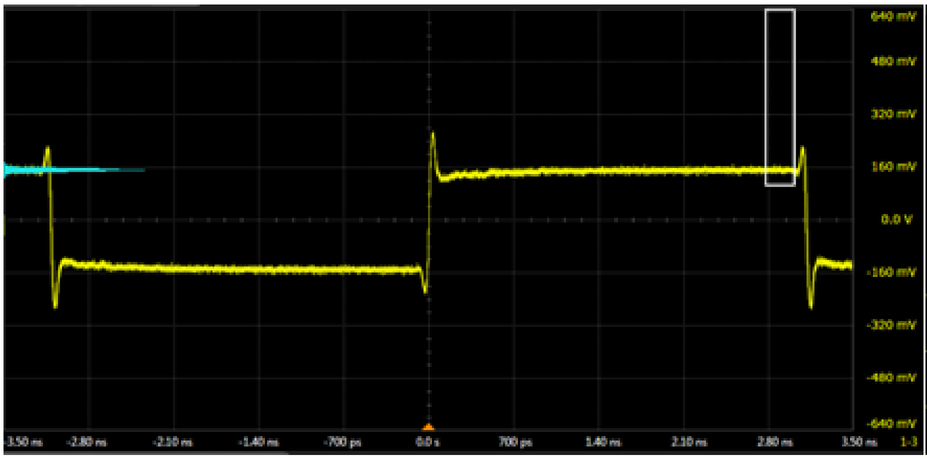
3.3.1.3 Test Objective

Confirm that the transmitter equalization falls within the limits of the USB4 Specification.

3.3.1.4 Test Method

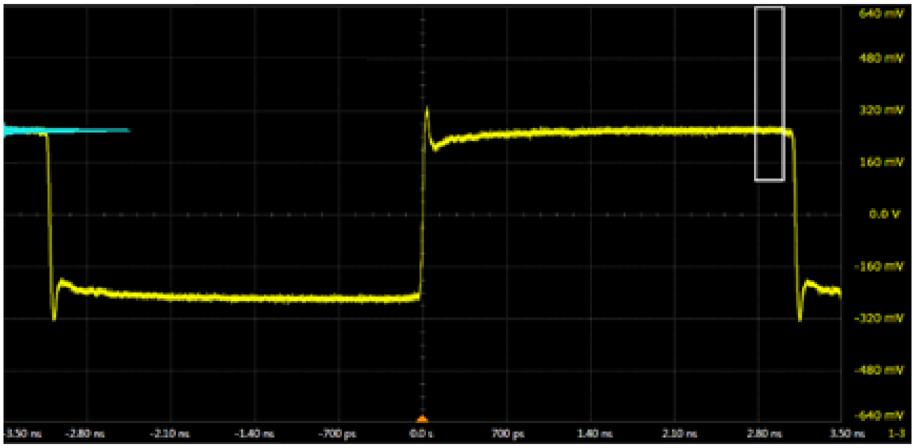
1. Set preset 0
2. Choose a supported USB4 Gen2 speed.
3. Scope BW shall be as specified in 6.1
4. The cables from the plug test fixture to the scope shall be de-embedded.

5. Configure DUT transmitter to output alternating square pattern of 64 0’s and 64 1’s on all lanes with SSC turned on with pre-shoot and with de-emphasis. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 with pre-shoot and with de-emphasis based on local clock without SSC modulation on all lanes.
6. Adjust vertical scale to fit signal into scope screen.
7. Use average of 150 cycles; no CDR and no interpolation to be used.

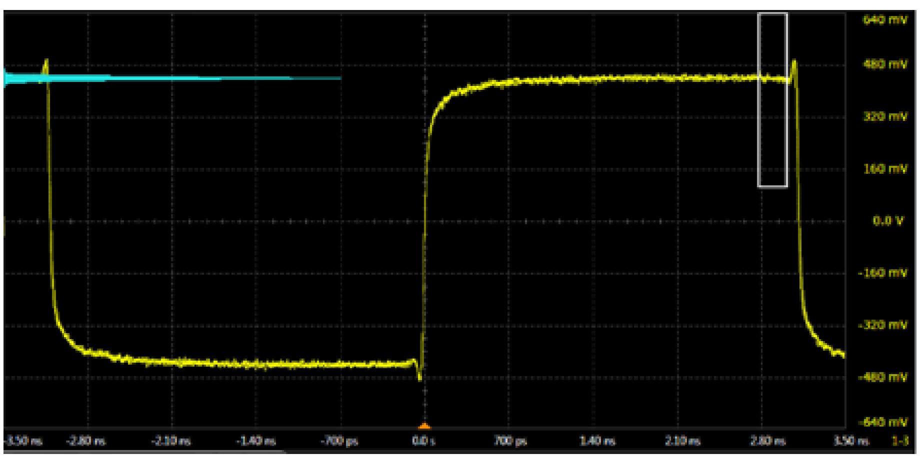


8. Measure differential amplitude voltage of bits 57-62 ($|V_{bits(57-62)}(64\ bits\ of\ 1's) - V_{bits(57-62)}(64\ bits\ of\ 0's)|$) ,average them and mark it as V_1.
9. Configure DUT transmitter to output alternating square pattern of 64 0’s and 64 1’s on all lanes with SSC turned on with no pre-shoot and with de-emphasis. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 with no pre-shoot and with de-emphasis based on local clock without SSC modulation on all lanes.
10. Adjust vertical scale to fit signal into scope screen.

11. Use average of 150 cycles; no CDR and no interpolation to be used.

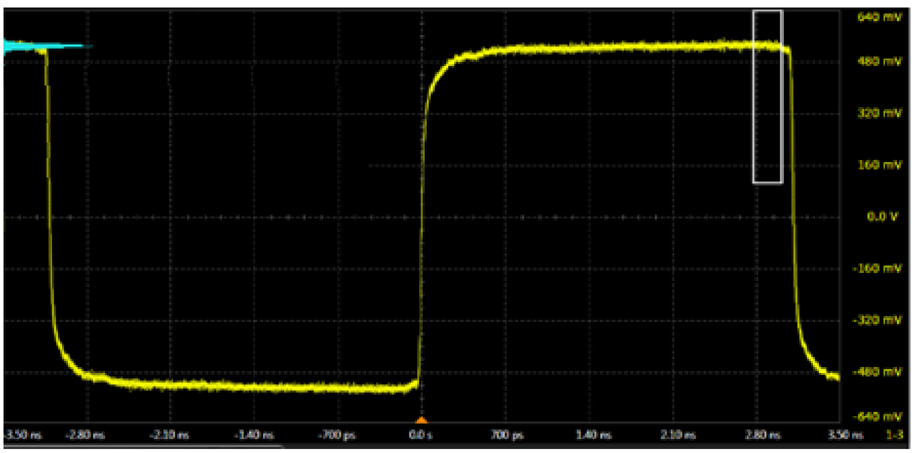


12. Measure differential amplitude voltage of bits 57-62 ($|V_{bits(57-62)}(64\ bits\ of\ 1's) - V_{bits(57-62)}(64\ bits\ of\ 0's)|$) ,average them and mark it as V_2.
13. Configure DUT transmitter to output alternating square pattern of 64 0's and 64 1's on all lanes with SSC turned on with pre-shoot but with no de-emphasis. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 with pre-shoot and with no de-emphasis based on local clock without SSC modulation on all lanes.
14. Adjust vertical scale to fit signal into scope screen.
15. Use average of 150 cycles; no CDR and no interpolation to be used.



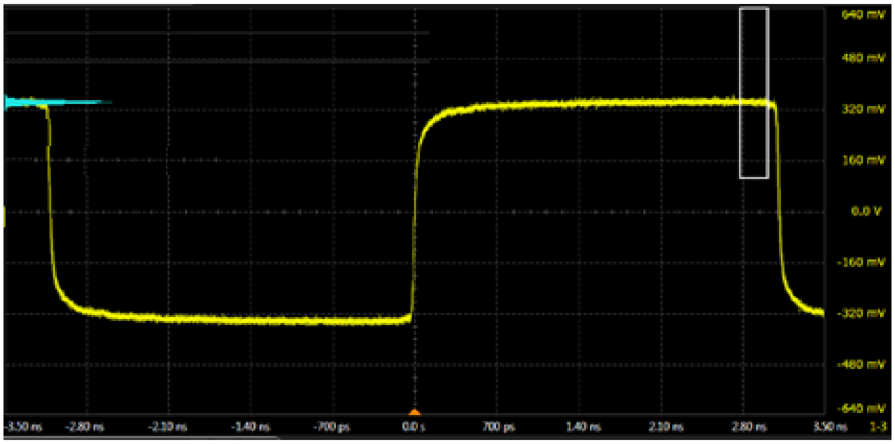
16. Measure differential amplitude voltage of bits 57-62 ($|V_{bits(57-62)}(64\ bits\ of\ 1's) - V_{bits(57-62)}(64\ bits\ of\ 0's)|$) ,average them and mark it as V_3.
17. Set Pre-shoot to be $20 * log_{10} {}^{V_2}/_{V_1}$
18. Set De-emphasis to be $20 * log_{10} {}^{V_1}/_{V_3}$

19. If Pre-shoot is not within ± 1dB of the matching value in the Transmit Equalization Preset Table then **Fail**
20. If De-emphasis is not within ± 1dB of the matching value in the Transmit Equalization Preset Table then **Fail**
21. Repeat for all Presets in the Transmit Equalization Preset Table.
22. Set the DUT to Preset 0.
23. Configure DUT transmitter to output alternating square pattern of 64 0’s and 64 1’s on all lanes with SSC turned on with no pre-shoot and with no de-emphasis. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 with no pre-shoot and with no de-emphasis based on local clock without SSC modulation on all lanes.
24. Adjust vertical scale to fit signal into scope screen.
25. Use average of 150 cycles; no CDR and no interpolation to be used.



26. Measure differential amplitude voltage of bits 57-62 ($|V_{bits(57-62)}(64\ bits\ of\ 1's) - V_{bits(57-62)}(64\ bits\ of\ 0's)|$) ,average them and mark it as V_0.
27. Set the DUT to Preset 15.
28. Configure DUT transmitter to output alternating square pattern of 64 0’s and 64 1’s on all lanes with SSC turned on with no pre-shoot and with no de-emphasis. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 with no pre-shoot and with no de-emphasis based on local clock without SSC modulation on all lanes.
29. Adjust vertical scale to fit signal into scope screen.

30. Use average of 150 cycles; no CDR and no interpolation to be used.



31. Measure differential amplitude voltage of bits 57-62 ($|V_{bits(57-62)}(64\ bits\ of\ 1's) - V_{bits(57-62)}(64\ bits\ of\ 0's)|$) ,average them and mark it as V_{15}.

32. Set Swing to be $20 * log_{10} {}^{V_0}/_{V_{15}}$

33. If Swing < 2.5 dB or Swing > 4.5 dB then **Fail**

34. Repeat the test for all remaining USB4 lanes.

3.3.2 Gen2 Minimum Unit Interval Measurement

3.3.2.1 Reference

UI - USB4 Specification Table 3-15

3.3.2.2 Requirement

99.97ps ≤ Minimum Unit Interval ≤ 100.03ps

3.3.2.3 Test Objective

Confirm that the Minimum Unit Interval under all conditions does not exceed minimum or maximum limits of the USB4 Specification during steady-state.

3.3.2.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the plug test fixture to the scope shall be de-embedded.
4. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - Scope BW shall be as specified in 6.1.
5. Minimum UI shall be calculated dynamically using a uniform moving average filter procedure with window size of 3000 symbols.
6. Capture 1 measurement and calculate both Min and Max of Minimum UI values.
7. If Max Minimum UI > 100.03ps **or** Min Minimum UI < 99.97ps then **Fail**
8. Repeat the test for all remaining USB4 lanes.

3.3.3 Gen2 SSC Down Spread Range Measurement

3.3.3.1 Reference

SSC_Down_Spread_Range - USB4 Specification Table 3-14

3.3.3.2 Requirement

0.4% ≤ SSC_Down_Spread_Range ≤ 0.5%

3.3.3.3 Test Objective

Confirm that the Dynamic range of SSC down-spreading during steady-state falls within the limits of the USB4 Specification.

3.3.3.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the plug test fixture to the scope shall be de-embedded.
4. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - Scope BW shall be as specified in 6.1.
5. UI shall be calculated dynamically using a uniform moving average filter procedure with window size of 3000 symbols.
6. Capture values of Max(maximum UI), Min(maximum UI), Max(minimum UI) and Min(minimum UI). calculate the Max and Min value of SSC_Down_Spread_Range:
    - Max(Max Deviation)= 100*((Bit_Rate - (1/ Max(maximum UI)))/ Bit_Rate)
    - Min(Min Deviation)= 100*((Bit_Rate - (1/ Min(minimum UI)))/ Bit_Rate)
    - Min(Max Deviation)= 100*((Bit_Rate - (1/ Min(maximum UI)))/ Bit_Rate)
    - Max(Min Deviation)= 100*((Bit_Rate - (1/ Max(minimum UI)))/ Bit_Rate)
    - Bit_Rate is the base frequency with 0ppm
    - Max SSC_Down_Spread_Range = Max(Max Deviation) – Min(Min Deviation)
    - Min SSC_Down_Spread_Range = Min(Max Deviation) – Max(Min Deviation)
7. If Max SSC_Down_Spread_Range > 0.5% **or** Min SSC_Down_Spread_Range < 0.4% then **Fail**
8. Repeat the test for all remaining USB4 lanes.

3.3.4 Gen2 SSC Down Spread Rate Measurement

3.3.4.1 Reference

SSC_Down_Spread_Rate - USB4 Specification Table 3-14

3.3.4.2 Requirement

30KHz ≤ SSC_Down_Spread_Rate ≤ 33KHz

3.3.4.3 Test Objective

Confirm that the SSC down-spreading modulation rate during steady-state falls within the limits of the USB4 Specification.

3.3.4.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the plug test fixture to the scope shall be de-embedded.
4. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - Scope BW shall be as specified in 6.1.
5. UI shall be calculated dynamically using a uniform moving average filter procedure with window size of 3000 symbols.
6. Capture values of Max SSC_Down_Spread_Rate and Min SSC_Down_Spread_Rate.
7. If 30KHz > Min SSC_Down_Spread_Rate **or** Max SSC_Down_Spread_Rate > 33KHz then **Fail**
8. Repeat the test for all remaining USB4 lanes.

3.3.5 Gen2 SSC Phase Deviation Measurement

3.3.5.1 Reference

SSC_Phase_Deviation - USB4 Specification Table 3-14

3.3.5.2 Requirement

2.5ns p-p ≤ SSC_Phase_Deviation ≤ 22ns p-p

3.3.5.3 Test Objective

Confirm that the Phase jitter associated with the SSC modulation during steady-state falls within the limits of the USB4 Specification.

3.3.5.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the plug test fixture to the scope shall be de-embedded.
4. Capture the waveform and post process it with an appropriate software:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used
    - Adjust vertical scale to fit signal into scope screen.
    - The SSC Phase deviation shall be extracted from the transmitted signal.
    - The SSC Phase deviation shall be extracted from the signal phase after applying a 2nd order Low-Pass-Filter (LPF) with 3dB point at 5MHz.
    - Scope BW shall be as specified in 6.1.
5. If SSC_Phase_Deviation < 2.5ns p-p or SSC_Phase_Deviation > 22ns p-p then **Fail**
6. Repeat the test for all remaining USB4 lanes.

3.3.6 Gen2 SSC Slew Rate Measurement

3.3.6.1 Reference

SSC_Slew_Rate - USB4 Specification Table 3-14

3.3.6.2 Requirement

SSC_Slew_Rate ≤ 1250 ppm/us

3.3.6.3 Test Objective

Confirm that the SSC Slew Rate during steady-state falls within the limits of the specification.

3.3.6.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the waveform and post process it with an appropriate software:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - The SSC slew rate shall be extracted from the transmitted signal over measurement intervals of 0.5us.
    - The SSC slew rate shall be extracted from the signal phase after applying a 2nd order Low-Pass-Filter (LPF) with 3dB point at 5MHz.
    - Scope BW shall be as specified in 6.1.
    - SSC_SLEW_RATE measurement shall be done in steady-state after the Link training phase is completed.
5. If SSC_Slew_Rate > 1250 ppm/us then **Fail**
6. Repeat the test for all remaining USB4 lanes.

3.3.7 Gen2 TX Frequency Variation Training Measurement

3.3.7.1 Reference

TX_FREQ_VARIATIONS_TRAINING – USB4 Specification Table 3-14

3.3.7.2 Requirement

TX_FREQ_VARIATIONS_TRAINING:
-300 ≤ INIT_FREQ_VARIATION ≤ 300 ppm
DELTA_FREQ_200ns ≤ 1400 ppm
DELTA_FREQ_1000ns ≤ 2200 ppm
FREQ_OVERSHOOT ≤ 1400 ppm

3.3.7.3 Test Objective

Confirm that the Frequency variation during Link training falls within the limits of the specification.
Note – this test should be applied only when the DUT contains Re-Timer.

3.3.7.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. For emulating link training, DUT shall be configured such that the Captive Device transmitting PRBS31 with SSC modulation on all lanes.
3. The Re-Timer placed near the USB Type-C connector shall be configured to transmit SQ2 based on local clock without SSC modulation on all lanes. If additional Re-Timer exist in the DUT, it shall be configured to transmit SQ4 based on local clock without SSC modulation on all lanes.
4. Initiate clock switch from local clock to recovered clock for the Re-Timer placed near the USB Type-C connector.
5. The cables from the test fixture to the scope should be de-embedded.
6. Capture the clock switch process during three stages: pre-clock switch, clock switch and post-clock switch in a single waveform and post process it as following:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - The frequency variation shall be performed over the transmitted signal.
    - The signal phase shall be extracted after applying a 2nd order Low-Pass-Filter (LPF) with 3dB point at 5MHz.

- Calculate the initial non-modulated transmit frequency aka INIT_FREQ_VARIATION.
- Calculate the FREQ_OVERSHOOT during Link training.
- Calculate the frequency variation during Link training (switch clock) over 200ns measurement windows aka DELTA_FREQ_200ns.
- Calculate the frequency variation during Link training (switch clock) over 1000ns measurement windows aka DELTA_FREQ_1000ns.
- Scope BW should be as specified in 6.1.

7. If additional Re-Timer exist in the DUT, then the 2nd clock switch needs to be analyzed as well from the saved waveform in step 6 above.
8. Repeat this procedure 20 times and report the worst captured waveform.
9. If INIT_FREQ_VARIATION > 300 ppm **or** INIT_FREQ_VARIATION < -300 ppm **or** FREQ_OVERSHOOT >1400 ppm **or** DELTA_FREQ_200ns >1400 ppm **or** DELTA_FREQ_1000ns > 2200 ppm then **Fail**
10. Repeat the test for all remaining USB4 lanes.

3.3.8 Gen2 Rise/Fall Time Measurement

3.3.8.1 Reference

RISE_FALL_TIME - USB4 Specification Table 3-14

3.3.8.2 Requirement

Rise Time and Fall Time ≥10ps

3.3.8.3 Test Objective

Confirm that the rise time and fall time on the USB4 differential signals falls within the limits of the USB4 Specification.

3.3.8.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output alternating square pattern of 64 0's and 64 1's (SQ128) on all lanes with SSC turned on. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 based on local clock without SSC modulation on all lanes.
3. The cables from the test fixture to the scope should be de-embedded.
4. Evaluate 4Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 4Mpts. The evaluated record length shall be 50us per channel
   - Scope BW shall be 21GHz.
   - No CDR, no average and no interpolation to be used.
   - Adjust vertical scale to fit signal into scope screen.
5. T_{RISE} and T_{FALL} measurement thresholds are 20% to 80% of the differential swing voltage.
6. Capture the minimum of T_{RISE} and T_{FALL}.
7. If T_{RISE} < 10ps **or** T_{FALL}< 10ps then **Fail**
8. Repeat the test for all remaining USB4 lanes.

3.3.9 Gen2 Electrical Idle Voltage Measurement

3.3.9.1 Reference

V_ELEC_IDLE - USB4 Specification Table 3-14

3.3.9.2 Requirement

V_ELEC_IDLE ≤ 20mV

3.3.9.3 Test Objective

Confirm that the TX peak voltage during transmit electrical idle do not exceed the limits of the USB4 Specification.

3.3.9.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT to be in electrical idle mode.
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the differential waveform V_{TX-P} - V_{TX-N} from the scope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 10Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 10Mpts. The evaluated record length shall be 125us per channel.
    - No CDR, no average and no interpolation to be used
    - Adjust vertical scale to fit signal into scope screen.
    - Scope BW shall be as specified in 6.1.
    - V_ELEC_IDLE shall be extracted after applying first order low-pass filter with 3 dB point at 1.25 GHz.
5. Measure V_{peak} (V_{TX-P} - V_{TX-N}).
6. If V_{peak} (V_{TX-P} - V_{TX-N}) > 20mV then **Fail**
7. Repeat the test for all remaining USB4 lanes.

3.3.10 Gen2 AC Common Mode Measurement

3.3.10.1 Reference

AC_CM - USB4 Specification Table 3-14

3.3.10.2 Requirement

AC_CM ≤ 200mVp-p

3.3.10.3 Test Objective

Confirm that the transmitter common mode on the USB4 differential signals falls within the limits of the USB4 Specification.

3.3.10.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 27Mpts. The evaluated record length shall be 337.5us per channel.
    - Adjust vertical scale to fit signal into scope screen.
    - No CDR, no average and no interpolation to be used.
    - Scope BW should be as specified in 6.1
5. $V_{AC-CM}=(V_{TX-P}+V_{TX-N})/2$
6. If V_{AC-CM} > 200mVp-p then **Fail**
7. Repeat the test for all remaining USB4 lanes.

3.3.11 Gen2 Total Jitter Measurement

3.3.11.1 Reference

TJ - USB4 Specification Table 3-15

3.3.11.2 Requirement

Total Jitter ≤ 0.60UIp-p

3.3.11.3 Test Objective

Confirm that the transmitter Total Jitter falls within the limits of the USB4 Specification.

3.3.11.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS15 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.
5. Measurement should be done with a reference CDR modeled by a 2^{nd} order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
6. TJ is defined as the sum of all "deterministic" components plus 14.7 times the RJ RMS. 14.7 is the factor that accommodates a Bit Error Ratio value of 1E-13
7. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
    - Pattern length -> Periodic
    - Jitter separation method shall be suitable for cross talk on signal
    - Adjust vertical scale to fit signal into scope screen.
    - Referenced to 1E-13 statistics.
    - Removing intrinsic scope noise and jitter is recommended.
8. Capture TJ and DJ result
9. If TJ > 0.60UIp-p
    i. Configure DUT transmitter to output alternating square pattern of 1 0's and 1 1's (SQ2) on all lanes with SSC turned on. Use the same setup as above (pattern SQ2 instead of PRBS15).

ii. Capture RJ result

iii. Calculate TJ to be TJ = DJ + 14.7*RJ (DJ from #8; PRBS15 and RJ from #9.2; SQ2)

10. If TJ > 0.60UIp-p then **Fail**

11. Repeat the test for all remaining USB4 lanes.

3.3.12 Gen2 UJ Measurement

3.3.12.1 Reference

UJ – USB4 Specification Table 3-15

3.3.12.2 Requirement

Sum of uncorrelated DJ and RJ components ≤ 0.31UIp-p

3.3.12.3 Test Objective

Confirm that the transmitter Sum of uncorrelated DJ and RJ components falls within the limits of the USB4 Specification.

3.3.12.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS15 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.
5. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
6. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
    - Pattern length -> Periodic
    - Jitter separation method shall be suitable for cross talk on signal
    - Adjust vertical scale to fit signal into scope screen.
    - Referenced to 1E-13 statistics.
    - Removing intrinsic scope noise and jitter is recommended.
7. Capture TJ and DDJ results. DDJ term definition is detailed in Appendix 9.2.
8. Calculate UJ=TJ-DDJ
9. If UJ > 0.31UIp-p then **Fail**
10. Repeat the test for all remaining USB4 lanes.

3.3.13 Gen2 UDJ Measurement

3.3.13.1 Reference

UDJ - USB4 Specification Table 3-15

3.3.13.2 Requirement

Deterministic jitter that is uncorrelated to the transmitted data ≤ 0.17UIp-p

3.3.13.3 Test Objective

Confirm that the transmitter Uncorrelated Deterministic Jitter falls within the limits of the USB4 Specification.

3.3.13.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS15 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.
5. Measurement should be done with a reference CDR modeled by a 2^{nd} order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
6. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
    - Pattern length -> Periodic
    - Jitter separation method shall be suitable for cross talk on signal
    - Adjust vertical scale to fit signal into scope screen.
7. Capture UDJ result
8. If UDJ > 0.17UIp-p then **Fail.**
9. Repeat the test for all remaining USB4 lanes.

3.3.14 Gen2 Low Frequency UDJ Measurement

3.3.14.1 Reference

UDJ_LF - USB4 Specification Table 3-15

3.3.14.2 Requirement

UDJ_LF ≤ 0.04UIp-p

3.3.14.3 Test Objective

Confirm that the transmitter low frequency Uncorrelated Deterministic Jitter falls within the limits of the USB4 Specification.

3.3.14.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS15 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.
5. Measurement shall be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; after that apply 2nd order Low-Pass-Filter (LPF) defined by $H(s) = \frac{2\zeta\omega_n s+\omega_n{}^2}{s^2+2\zeta\omega_n s+\omega_n{}^2}$ Where ζ =3.5; ω_n=4.4e5 ; no average and no interpolation to be used. Scope BW shall be as specified in 6.1.
6. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
    - Pattern length -> Periodic
    - Jitter separation method shall be suitable for cross talk on signal
    - Adjust vertical scale to fit signal into scope screen.
7. Capture UDJ_LF result
8. If UDJ_LF > 0.04UIp-p then **Fail**
9. Repeat the test for all remaining USB4 lanes

3.3.15 Gen2 DCD Measurement

3.3.15.1 Reference

DCD - USB4 Specification Table 3-15

3.3.15.2 Requirement

DCD ≤ 0.03UIp-p

3.3.15.3 Test Objective

Confirm that the transmitter Deterministic Jitter Associated by Duty-Cycle-Distortion Jitter falls within the limits of the USB4 Specification.

3.3.15.4 Test Method

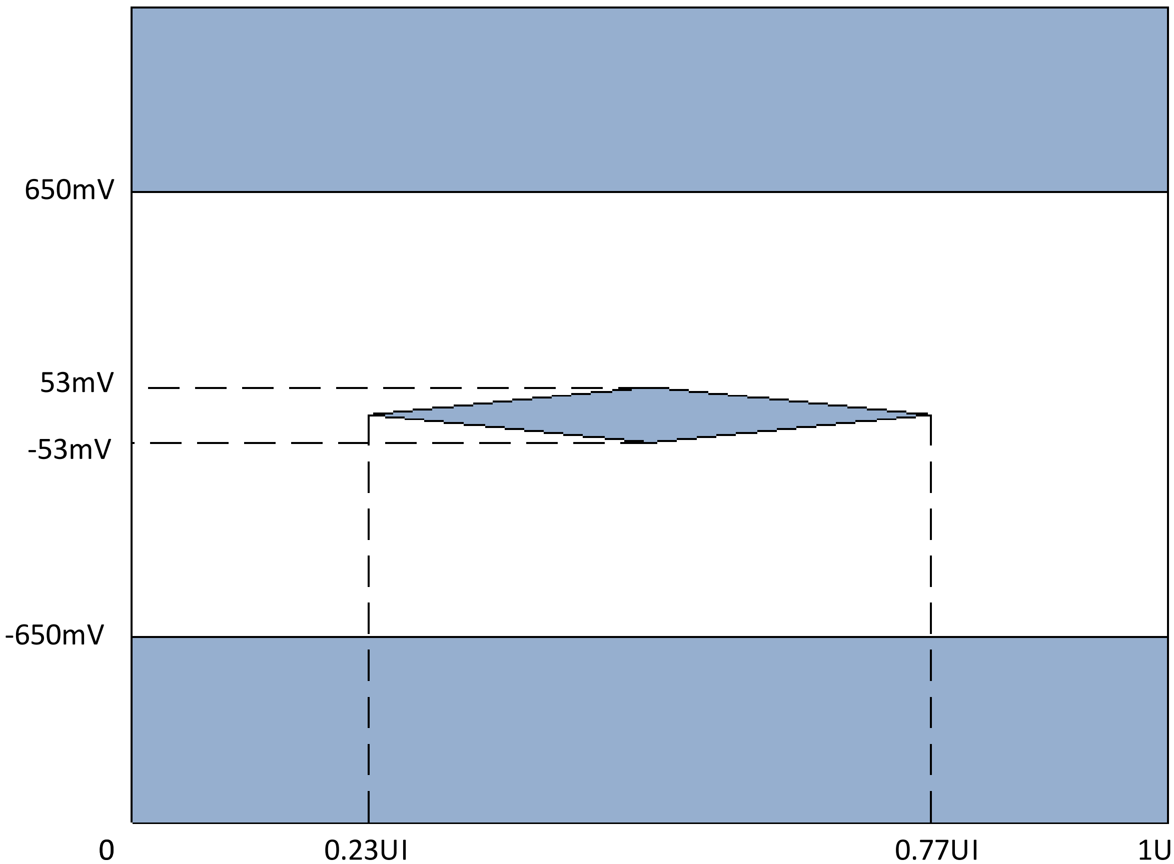
1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS15 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.
5. Measurement should be done with a reference CDR modeled by a 2^{nd} order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
6. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
    - Pattern length -> Periodic
    - Jitter separation method shall be suitable for cross talk on signal
    - Adjust vertical scale to fit signal into scope screen.
7. Capture DCD (Even-Odd jitter) result. DCD term definition is detailed in Appendix 9.3.
8. If DCD > 0.03UIp-p then **Fail**
9. Repeat the test for all remaining USB4 lanes

3.3.16 Gen2 Eye Diagram Measurement

3.3.16.1 Reference

Eye Diagram Mask – USB4 Specification Table 3-15
USB4 Specification Figure 3-14 – TX Mask Notations.

3.3.16.2 Requirement



3.3.16.3 Test Objective

Confirm that the differential signal on each USB4 differential lane has an eye opening that meets or exceeds the limits on the eye opening in the USB4 Specification.

3.3.16.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.

5. Measurement shall be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; interpolation shall be applied for obtaining effective sample rate of 1280GSa/s (e.g. X16 interpolation for 80GSa/s hardware sampling rate). Scope BW shall be as specified in 6.1.
6. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Adjust vertical and horizontal scale to fit signal into scope screen.
    - Measured 1E6 UI
7. Compare the data eye to the eye diagram mask, If any part of the waveform hits the mask then **Fail.**
8. Repeat the test for all remaining USB4 lanes.

3.3.17 Gen2 Wireless Band Conducted Measurement

3.3.17.1 Reference

Wireless Band Conducted - Thunderbolt Interconnect Specification Table 3-13

3.3.17.2 Requirement

PWR_diff_1-14≤-17dBm
PWR_comm_1-14≤-47dBm
PWR_diff_36-64≤-22dBm
PWR_comm_36-64≤-43dBm
PWR_diff_100-140≤-23dBm
PWR_comm_100-140≤-44dBm
PWR_diff_149-165≤-23dBm
PWR_comm_149-165≤-45dBm

3.3.17.3 Test Objective

Confirm that the Wireless Band Conducted under all conditions does not exceed maximum limits of the USB4 Specification.

3.3.17.4 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5us per channel.
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - Scope BW should be as specified in 6.1.
5. Perform an FFT of the differential and common mode math functions on the oscilloscope
    - Set the frequency span per Table 3-12 of the USB4 Specification
    - Measured in 18MHz window around the center frequency
    - Use Flat Top filter window
    - Set the averaging to 256
6. If PWR_diff_1-14>-17dBm or PWR_comm_1-14>-47dBm or PWR_diff_36-64>-22dBm or PWR_comm_36-64>-43dBm or PWR_diff_100-140>-23dBm or PWR_comm_100-140>-44dBm or PWR_diff_149-165>-23dBm or PWR_comm_149-165>-45dBm then **Fail**
7. Repeat the test for all remaining USB4 lanes.

3.4 Gen 3 Captive Device Transmitter Compliance

Note: Refer to Sections 3 - 3.2 for test Setup.

3.4.1 Transmitter Equalization

3.4.1.1 Reference

USB4 Specification Table 3-14 and 3-5 (reproduced above).

3.4.1.2 Requirement

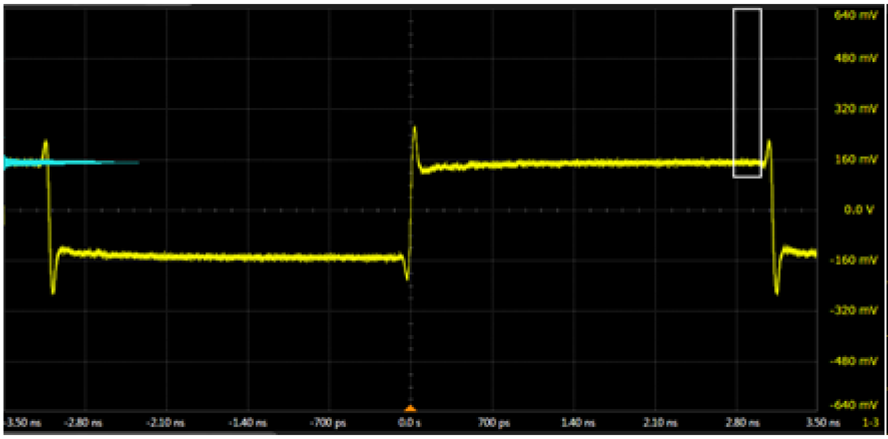
Transmitter swing 3.5 ± 1dB (for preset 15 only)
Pre-shoot, de-emphasis ± 1dB for the presets in the Transmit Equalization Preset Table above.

3.4.1.3 Test Objective

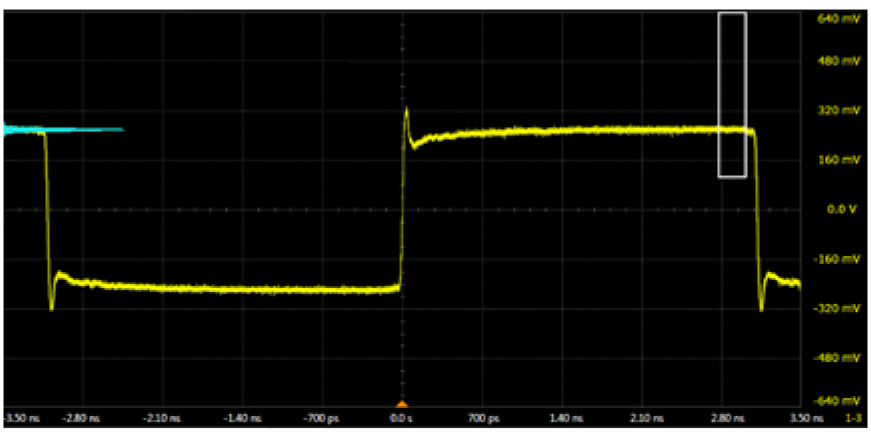
Confirm that the transmitter equalization falls within the limits of the USB4 Specification.

3.4.1.4 Test Method

1. Set preset 0
2. Choose a supported USB4 Gen3 speed.
3. Scope BW should be as specified in 6.1
4. The cables from the test fixture to the scope should be de-embedded.
5. Configure DUT transmitter to output alternating square pattern of 64 0's and 64 1's on all lanes with SSC turned on with pre-shoot and with de-emphasis. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 with pre-shoot and with de-emphasis based on local clock without SSC modulation on all lanes.
6. Adjust vertical scale to fit signal into scope screen.
7. Average one cycle using 150 cycles; no CDR and no interpolation to be used.

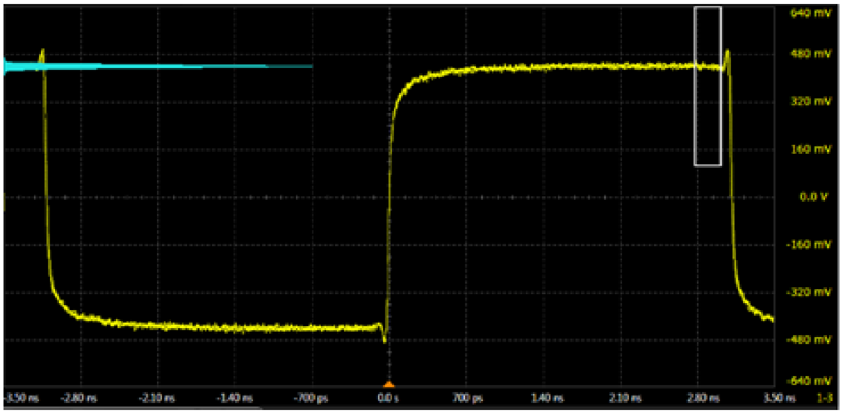


8. Measure differential amplitude voltage of bits 57-62 ($|V_{bits(57-62)}(64\ bits\ of\ 1's) - V_{bits(57-62)}(64\ bits\ of\ 0's)|$) average them and mark it as V_1.
9. Configure DUT transmitter to output alternating square pattern of 64 0's and 64 1's on all lanes with SSC turned on with no pre-shoot and with de-emphasis. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 with no pre-shoot and with de-emphasis based on local clock without SSC modulation on all lanes.
10. Adjust vertical scale to fit signal into scope screen.
11. Average one cycle using 150 cycles; no CDR and no interpolation to be used.

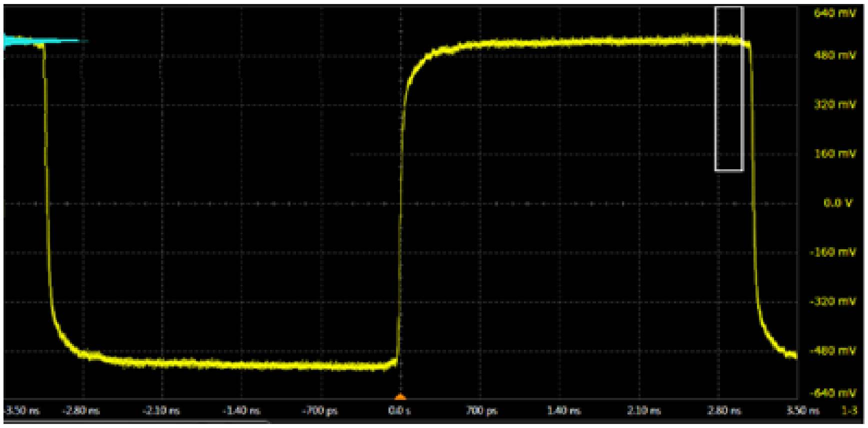


12. Measure differential amplitude voltage of bits 57-62 ($|V_{bits(57-62)}(64\ bits\ of\ 1's) - V_{bits(57-62)}(64\ bits\ of\ 0's)|$) average them and mark it as V_2.
13. Configure DUT transmitter to output alternating square pattern of 64 0's and 64 1's on all lanes with SSC turned on with pre-shoot but with no de-emphasis. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 with pre-shoot and with no de-emphasis based on local clock without SSC modulation on all lanes.

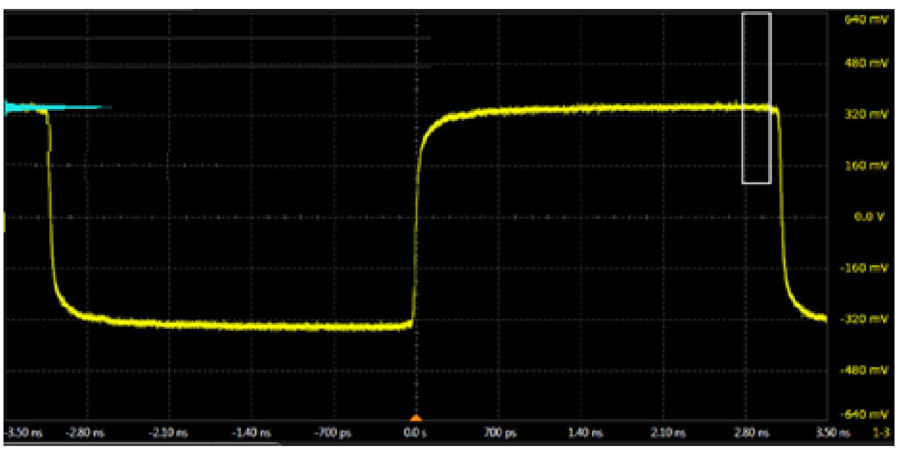
14. Adjust vertical scale to fit signal into scope screen.
15. Average one cycle using 150 cycles; no CDR and no interpolation to be used.



16. Measure differential amplitude voltage of bits 57-62 ($|V_{bits(57-62)}(64\ bits\ of\ 1's) - V_{bits(57-62)}(64\ bits\ of\ 0's)|$) average them and mark it as V_3.
17. Set Pre-shoot to be $20 * log_{10} {}^{V_2}/_{V_1}$
18. Set De-emphasis to be $20 * log_{10} {}^{V_1}/_{V_3}$
19. If Pre-shoot is not within ± 1dB of the matching value in the Transmit Equalization Preset Table then **Fail**
20. If De-emphasis is not within ± 1dB of the matching value in the Transmit Equalization Preset Table then **Fail**
21. Repeat for all Presets in the Transmit Equalization Preset Table.
22. Set the DUT to preset 0.
23. Configure DUT transmitter to output alternating square pattern of 64 0's and 64 1's on all lanes with SSC turned on with no pre-shoot and with no de-emphasis. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 with no pre-shoot and with no de-emphasis based on local clock without SSC modulation on all lanes.
24. Adjust vertical scale to fit signal into scope screen.
25. Average one cycle using 150 cycles; no CDR and no interpolation to be used.



26. Measure differential amplitude voltage of bits 57-62 ($|V_{bits(57-62)}(64\ bits\ of\ 1's) - V_{bits(57-62)}(64\ bits\ of\ 0's)|$) average them and mark it as V_0.
27. Set the DUT to preset 15.
28. Configure DUT transmitter to output alternating square pattern of 64 0's and 64 1's on all lanes with SSC turned on with no pre-shoot and with no de-emphasis. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 with no pre-shoot and with no de-emphasis based on local clock without SSC modulation on all lanes.
29. Adjust vertical scale to fit signal into scope screen.
30. Average one cycle using 150 cycles; no CDR and no interpolation to be used.



31. Measure differential amplitude voltage of bits 57-62 ($|V_{bits(57-62)}(64\ bits\ of\ 1's) - V_{bits(57-62)}(64\ bits\ of\ 0's)|$) and average them mark it as V_{15}.
32. Set Swing to be $20 * log_{10} {V_0}/{V_{15}}$
33. If Swing < 2.5 dB or Swing > 4.5 dB then **Fail**
34. Repeat the test for all remaining USB4 lanes.

3.4.2 Gen3 Minimum Unit Interval Measurement

3.4.2.1 Reference

UI USB4 Specification Table 3-16.

3.4.2.2 Requirement

49.985ps ≤ Minimum Unit Interval ≤ 50.015ps

3.4.2.3 Test Objective

Confirm that the Minimum Unit Interval under all conditions does not exceed minimum or maximum limits of the USB4 Specification.

3.4.2.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - Scope BW should be as specified in 6.1.
5. Minimum UI should be calculated dynamically using a uniform moving average filter procedure with window size of 6000 symbols.
6. Capture 1 measurement and calculate both Min and Max of Minimum UI values.
7. If Max Minimum UI > 50.015ps **or** Min Minimum UI < 49.985ps then **Fail**
8. Repeat the test for all remaining USB4 lanes

3.4.3 Gen3 SSC Down Spread Range Measurement

3.4.3.1 Reference

SSC_Down_Spread_Range - USB4 Specification Table 3-14

3.4.3.2 Requirement

0.4% ≤ SSC_Down_Spread_Range ≤ 0.5%

3.4.3.3 Test Objective

Confirm that the Dynamic range of SSC down-spreading falls within the limits of the USB4 Specification.

3.4.3.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5us per channel
   - No CDR, no average and no interpolation to be used.
   - Adjust vertical scale to fit signal into scope screen.
   - Scope BW should be as specified in 6.1.
5. UI should be calculated dynamically using a uniform moving average filter procedure with window size of 6000 symbols.
6. Capture values of Max(maximum UI), Min(maximum UI), Max(minimum UI) and Min(minimum UI). calculate the Max and Min value of SSC_Down_Spread_Range:
   - Max(Max Deviation)= 100*((Bit_Rate - (1/ Max(maximum UI)))/ Bit_Rate)
   - Min(Min Deviation)= 100*((Bit_Rate - (1/ Min(minimum UI)))/ Bit_Rate)
   - Min(Max Deviation)= 100*((Bit_Rate - (1/ Min(maximum UI)))/ Bit_Rate)
   - Max(Min Deviation)= 100*((Bit_Rate - (1/ Max(minimum UI)))/ Bit_Rate)
   - Bit_Rate is the base frequency with 0ppm
   - Max SSC_Down_Spread_Range = Max(Max Deviation) – Min(Min Deviation)
   - Min SSC_Down_Spread_Range = Min(Max Deviation) – Max(Min Deviation)
7. If SSC_Down_Spread_Range > 0.5% **or** SSC_Down_Spread_Range < 0.4% then **Fail**
8. Repeat the test for all remaining USB4 lanes.

3.4.4 Gen3 SSC Down Spread Rate Measurement

3.4.4.1 Reference

SSC_Down_Spread_Rate - USB4 Specification Table 3-14

3.4.4.2 Requirement

30KHz ≤ SSC_Down_Spread_Rate ≤ 33KHz

3.4.4.3 Test Objective

Confirm that the SSC down-spreading modulation rate during steady-state falls within the limits of the USB4 Specification.

3.4.4.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - Scope BW should be as specified in 6.1.
5. UI shall be calculated dynamically using a uniform moving average filter procedure with window size of 3000 symbols.
6. Capture values of Max SSC_Down_Spread_Rate and Min SSC_Down_Spread_Rate.
7. If 30KHz > SSC_Down_Spread_Rate **or** SSC_Down_Spread_Rate > 33KHz then **Fail**
8. Repeat the test for all remaining USB4 lanes.

3.4.5 Gen3 SSC Phase Deviation Measurement

3.4.5.1 Reference

SSC_Phase_Deviation - USB4 Specification Table 3-14

3.4.5.2 Requirement

2.5ns p-p ≤ SSC_Phase_Deviation ≤ 22ns p-p

3.4.5.3 Test Objective

Confirm that the Phase jitter associated with the SSC modulation during steady-state falls within the limits of the USB4 Specification.

3.4.5.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the waveform and post process it with an appropriate software:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used
    - Adjust vertical scale to fit signal into scope screen.
    - The SSC phase Deviation should be extracted from the transmitted signal.
    - The SSC phase Deviation should be extracted from the phase jitter after applying a 2nd order Low-Pass-Filter (LPF) with 3dB point at 5MHz.
    - Scope BW should be as specified in 6.1
5. If SSC_Phase_Deviation < 2.5ns p-p or SSC_Phase_Deviation > 22ns p-p then **Fail** then **Fail**
6. Repeat the test for all remaining USB4 lanes.

3.4.6 Gen3 SSC Slew Rate Measurement

3.4.6.1 Reference

SSC_Slew_Rate - USB4 Specification Table 3-14

3.4.6.2 Requirement

SSC_Slew_Rate ≤ 1250 ppm/us

3.4.6.3 Test Objective

Confirm that the SSC Slew Rate during steady-state falls within the limits of the specification.

3.4.6.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the waveform and post process it with an appropriate software:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - The SSC slew rate shall be extracted from the transmitted signal over measurement intervals of 0.5us.
    - The SSC slew rate shall be extracted from the phase information after applying a 2nd order Low-Pass-Filter (LPF) with 3dB point at 5MHz.
    - Scope BW should be as specified in 6.1.
    - SSC_SLEW_RATE measurement should be done in steady-state after the Link training phase is completed.
5. If SSC_Slew_Rate > 1250 ppm/us then **Fail**
6. Repeat the test for all remaining USB4 lanes.

3.4.7 Gen3 TX Frequency Variation Training Measurement

3.4.7.1 Reference

TX_FREQ_VARIATIONS_TRAINING – USB4 Specification Table 3-14

3.4.7.2 Requirement

TX_FREQ_VARIATIONS_TRAINING:
-300 ≤ INIT_FREQ_VARIATION ≤ 300 ppm
DELTA_FREQ_200ns ≤ 1400 ppm
DELTA_FREQ_1000ns ≤ 2200 ppm
FREQ_OVERSHOOT ≤ 1400 ppm

3.4.7.3 Test Objective

Confirm that the Frequency variation during Link training falls within the limits of the specification.
Note – this test should be applied only when the DUT contains Re-Timer.

3.4.7.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. For emulating link training, DUT shall be configured such that the Captive Device transmitting PRBS31 with SSC modulation on all lanes.
3. The Re-Timer placed near the USB Type-C connector shall be configured to transmit SQ2 based on local clock without SSC modulation on all lanes. If additional Re-Timer exist in the DUT, it shall be configured to transmit SQ4 based on local clock without SSC modulation on all lanes.
4. Initiate clock switch from local clock to recovered clock for the Re-Timer placed near the USB Type-C connector.
5. The cables from the test fixture to the scope should be de-embedded.
6. Capture the clock switch process during three stages: pre-clock switch, clock switch and post-clock switch in a single waveform and post process it as following:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5us per channel
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - The frequency variation shall be performed over the transmitted signal.
    - The signal phase shall be extracted after applying a 2nd order Low-Pass-Filter (LPF) with 3dB point at 5MHz.

- Calculate the initial non-modulated transmit frequency aka INIT_FREQ_VARIATION.
- Calculate the FREQ_OVERSHOOT during Link training.
- Calculate the frequency variation during Link training (switch clock) over 200ns measurement windows aka DELTA_FREQ_200ns.
- Calculate the frequency variation during Link training (switch clock) over 1000ns measurement windows aka DELTA_FREQ_1000ns.
- Scope BW should be as specified in 6.1.

7. If additional Re-Timer exist in the DUT, then the 2^{nd} clock switch needs to be analyzed as well from the saved waveform in step 6 above.
8. Repeat this procedure 20 times and report the worst captured waveform.
9. If INIT_FREQ_VARIATION > 300 ppm **or** INIT_FREQ_VARIATION < -300 ppm **or** FREQ_OVERSHOOT >1400 ppm **or** DELTA_FREQ_200ns >1400 ppm **or** DELTA_FREQ_1000ns > 2200 ppm then **Fail**.
10. Repeat the test for all remaining USB4 lanes.

3.4.8 Gen3 Rise/Fall Time Measurement

3.4.8.1 Reference

RISE_FALL_TIME - USB4 Specification Table 3-14

3.4.8.2 Requirement

Rise Time and Fall Time ≥10ps

3.4.8.3 Test Objective

Confirm that the rise times and fall times on the USB4 differential signals falls within the limits of the USB4 Specification.

3.4.8.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output alternating square pattern of 64 0's and 64 1's (SQ128) on all lanes with SSC turned on. If a Re-Timer placed near the USB Type-C connector, then the Re-Timer transmitter shall be configured to transmit SQ128 based on local clock without SSC modulation on all lanes.
3. The cables from the test fixture to the scope should be de-embedded.
4. Evaluate 4Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 4Mpts. The evaluated record length shall be 50us per channel
    - Scope BW shall be 21GHz.
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
5. T_{RISE} and T_{FALL} measurement thresholds are 20% to 80% of the differential swing voltage.
6. Capture the minimum of T_{RISE} and T_{FALL}.
7. If T_{RISE} < 10ps **or** T_{FALL}< 10ps then **Fail**
8. Repeat the test for all remaining USB4 lanes.

3.4.9 Gen3 Electrical Idle Voltage Measurement

3.4.9.1 Reference

V_ELEC_IDLE - USB4 Specification Table 3-14

3.4.9.2 Requirement

V_ELEC_IDLE ≤ 20mV

3.4.9.3 Test Objective

Confirm that the TX peak voltage during transmit electrical idle do not exceed the limits of the USB4 Specification.

3.4.9.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT to be in electrical idle mode.
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the differential waveform V_{TX-P} - V_{TX-N} from the scope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 10Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 10Mpts. The evaluated record length shall be 125us per channel.
   - No CDR, no average and no interpolation to be used
   - Adjust vertical scale to fit signal into scope screen.
   - Scope BW shall be as specified in 6.1.
   - V_ELEC_IDLE shall be extracted after applying first order low-pass filter with 3 dB point at 1.25 GHz.
5. Measure V_{peak} (V_{TX-P} - V_{TX-N}).
6. If V_{peak} (V_{TX-P} - V_{TX-N}) > 20mV then **Fail**
7. Repeat the test for all remaining USB4 lanes.

3.4.10 Gen3 AC Common Mode Measurement

3.4.10.1 Reference

AC_CM - USB4 Specification Table 3-14

3.4.10.2 Requirement

AC_CM ≤ 200mVp-p

3.4.10.3 Test Objective

Confirm that the transmitter common mode on the USB4 differential signals falls within the limits of the USB4 Specification.

3.4.10.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. he evaluated record length shall be 337.5us per channel.
    - Adjust vertical scale to fit signal into scope screen.
    - No CDR, no average and no interpolation to be used.
    - Scope BW should be as specified in 6.1
5. $V_{AC-CM}=(V_{TX-P}+V_{TX-N})/2$
6. If V_{AC-CM} > 200mVp-p then **Fail**
7. Repeat the test for all remaining USB4 lanes.

3.4.11 Gen3 Total Jitter Measurement

3.4.11.1 Reference

TJ - USB4 Specification Table 3-16

3.4.11.2 Requirement

Total Jitter ≤ 0.60UIp-p

3.4.11.3 Test Objective

Confirm that the transmitter Total Jitter falls within the limits of the USB4 Specification.

3.4.11.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS15 on all lanes with SSC turned on
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.
5. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
6. TJ is defined as the sum of all "deterministic" components plus 14.7 times the RJ RMS. 14.7 is the factor that accommodates a Bit Error Ratio value of 1E-13
7. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
   - Pattern length -> Periodic
   - Jitter separation method shall be suitable for cross talk on signal
   - Adjust vertical scale to fit signal into scope screen.
   - Referenced to 1E-13 statistics.
   - Removing intrinsic scope noise and jitter is recommended.
8. Capture TJ and DJ result
9. If TJ > 0.60UIp-p
   i. Configure DUT transmitter to output alternating square pattern of 1 0's and 1 1's (SQ2) on all lanes with SSC turned on. Use the same setup as above (pattern SQ2 instead of PRBS15).

ii. Capture RJ result.

iii. Calculate TJ to be TJ = DJ + 14.7*RJ (DJ from #8; PRBS15 and RJ from #9.2; SQ2)

10. If TJ > 0.60UIp-p then **Fail**
11. Repeat the test for all remaining USB4 lanes.

3.4.12 Gen3 UJ Measurement

3.4.12.1 Reference

UJ – USB4 Specification Table 3-16

3.4.12.2 Requirement

Sum of uncorrelated DJ and RJ components ≤ 0.31UIp-p

3.4.12.3 Test Objective

Confirm that the transmitter Sum of uncorrelated DJ and RJ components falls within the limits of the USB4 Specification.

3.4.12.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS15 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.
5. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
6. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
    - Pattern length -> Periodic
    - Jitter separation method shall be suitable for cross talk on signal
    - Adjust vertical scale to fit signal into scope screen.
    - Referenced to 1E-13 statistics.
    - Removing intrinsic scope noise and jitter is recommended.
7. Capture TJ and DDJ results. DDJ term definition is detailed in Appendix 9.2.
8. Calculate UJ=TJ-DDJ
9. If UJ > 0.31UIp-p then **Fail**
10. Repeat the test for all remaining USB4 lanes.

3.4.13 Gen3 UDJ Measurement

3.4.13.1 Reference

UDJ - USB4 Specification Table 3-16

3.4.13.2 Requirement

Deterministic jitter that is uncorrelated to the transmitted data ≤ 0.17UIp-p

3.4.13.3 Test Objective

Confirm that the transmitter Uncorrelated Deterministic Jitter falls within the limits of the USB4 Specification.

3.4.13.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS15 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.
5. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
6. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
   - Pattern length -> Periodic
   - Jitter separation method shall be suitable for cross talk on signal
   - Adjust vertical scale to fit signal into scope screen.
7. Capture UDJ result
8. If UDJ > 0.17UIp-p then **Fail**
9. Repeat the test for all remaining USB4 lanes.

3.4.14 Gen3 Low Frequency UDJ Measurement

3.4.14.1 Reference

UDJ_LF - USB4 Specification Tables 3-16

3.4.14.2 Requirement

UDJ_LF ≤ 0.07UIp-p

3.4.14.3 Test Objective

Confirm that the transmitter low frequency Uncorrelated Deterministic Jitter falls within the limits of the USB4 Specification.

3.4.14.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS15 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.
5. Measurement shall be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; after that apply 2nd order Low-Pass-Filter (LPF) defined by $H(s) = \frac{2\zeta\omega_n s+\omega_n{}^2}{s^2+2\zeta\omega_n s+\omega_n{}^2}$ Where ζ =3.5; ω_n=4.4e5 ; no average and no interpolation to be used. Scope BW shall be as specified in 6.1.
6. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
   - Pattern length -> Periodic
   - Jitter separation method shall be suitable for cross talk on signal
   - Adjust vertical scale to fit signal into scope screen.
7. Capture UDJ_LF result.
8. If UDJ_LF > 0.07UIp-p then **Fail**
9. Repeat the test for all remaining USB4 lanes.

3.4.15 Gen3 DCD Measurement

3.4.15.1 Reference

DCD - USB4 Specification Tables 3-16

3.4.15.2 Requirement

DCD ≤ 0.03UIp-p

3.4.15.3 Test Objective

Confirm that the transmitter Deterministic Jitter Associated by Duty-Cycle-Distortion Jitter falls within the limits of the USB4 Specification.

3.4.15.4 Test Method

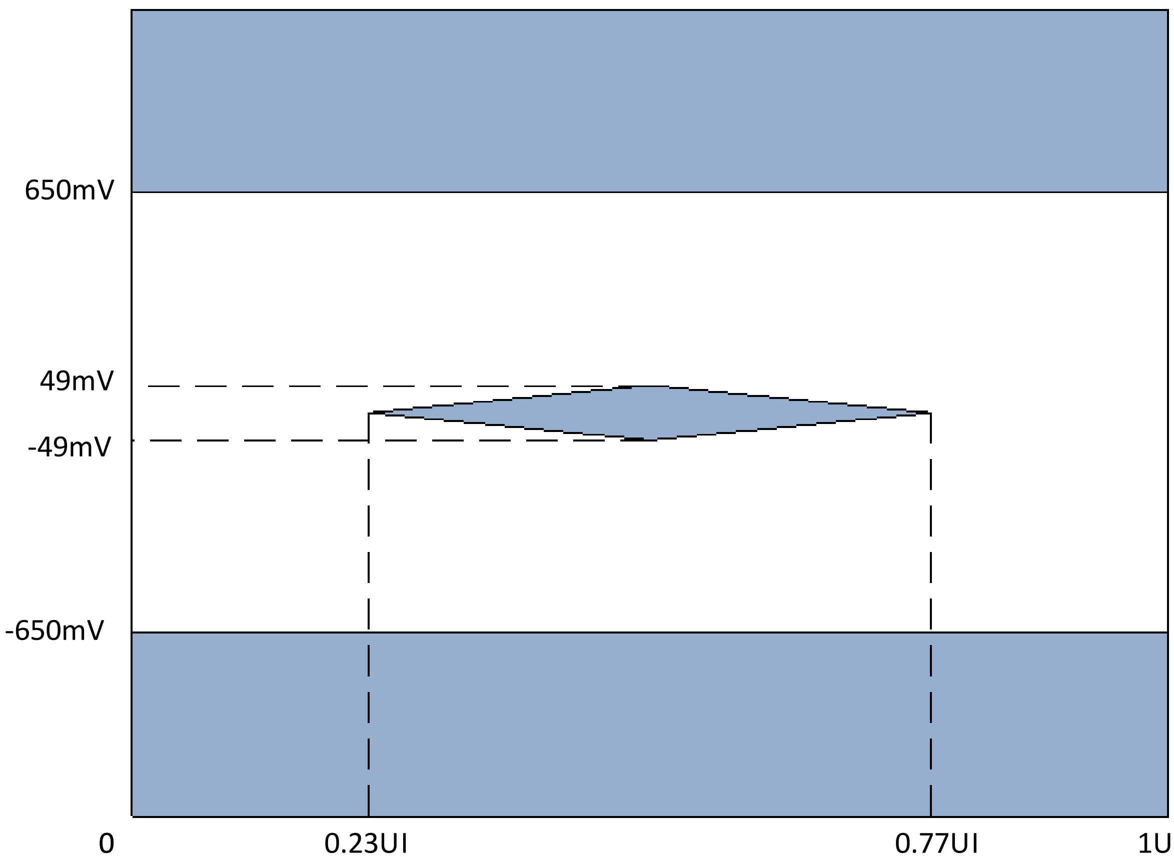
1. Choose a supported USB4 Gen3 speed to start with.
2. Configure DUT transmitter to output PRBS15 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B
5. Measurement should be done with a reference CDR modeled by a 2^{nd} order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
6. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
    - Pattern length -> Periodic
    - Jitter separation method shall be suitable for cross talk on signal
    - Adjust vertical scale to fit signal into scope screen.
7. Capture DCD (Even-Odd jitter) result. DCD term definition is detailed in Appendix 9.3
8. If DCD > 0.03UIp-p then **Fail**.
9. Repeat the test for all remaining USB4 lanes.

3.4.16 Gen3 Eye Diagram Measurement

3.4.16.1 Reference

Eye Diagram Mask – USB4 Specification Table 3-16
USB4 Specification Figure 3-14 – TX Mask Notations.

3.4.16.2 Requirement



3.4.16.3 Test Objective

Confirm that the differential signal on each USB4 differential lane has an eye opening that meets or exceeds the limits on the eye opening in the USB4 Specification.

3.4.16.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the test fixture to the scope should be de-embedded.
4. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.

5. Measurement shall be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; interpolation shall be applied for obtaining effective sample rate of 1280GSa/s (e.g. X16 interpolation for 80GSa/s hardware sampling rate). Scope BW shall be as specified in 6.1.
6. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Adjust vertical and horizontal scale to fit signal into scope screen.
    - Measured 1E6 UI
7. Compare the data eye to the eye diagram mask. If any part of the waveform hits the mask, then **Fail**
8. Repeat the test for all remaining USB4 lanes.

3.4.17 Gen3 Wireless Band Conducted Measurement

3.4.17.1 Reference

Wireless Band Conducted - Thunderbolt Interconnect Specification Table 3-13

3.4.17.2 Requirement

PWR_diff_1-14≤-17dBm
PWR_comm_1-14≤-47dBm
PWR_diff_36-64≤-22dBm
PWR_comm_36-64≤-43dBm
PWR_diff_100-140≤-23dBm
PWR_comm_100-140≤-44dBm
PWR_diff_149-165≤-23dBm
PWR_comm_149-165≤-45dBm

3.4.17.3 Test Objective

Confirm that the Wireless Band Conducted under all conditions does not exceed maximum limits of the USB4 Specification.

3.4.17.4 Test Method

1. Choose a supported USB4 Gen3 speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5us per channel.
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - Scope BW should be as specified in 6.1.
4. Perform an FFT of the differential and common mode math functions on the oscilloscope
    - Set the frequency span per Table 3-12 of the Thunderbolt Interconnect Specification
    - Measured in 18MHz window around the center frequency
    - Use Flat Top filter window
    - Set the averaging to 256
5. If PWR_diff_1-14>-17dBm or PWR_comm_1-14>-47dBm or PWR_diff_36-64>-22dBm or PWR_comm_36-64>-43dBm or PWR_diff_100-140>-23dBm or PWR_comm_100-140>-44dBm or PWR_diff_149-165>-23dBm or PWR_comm_149-165>-45dBm then **Fail**
6. Repeat the test for all remaining USB4 lanes.

3.5 Transmitter Return Loss Gen2 and Gen3

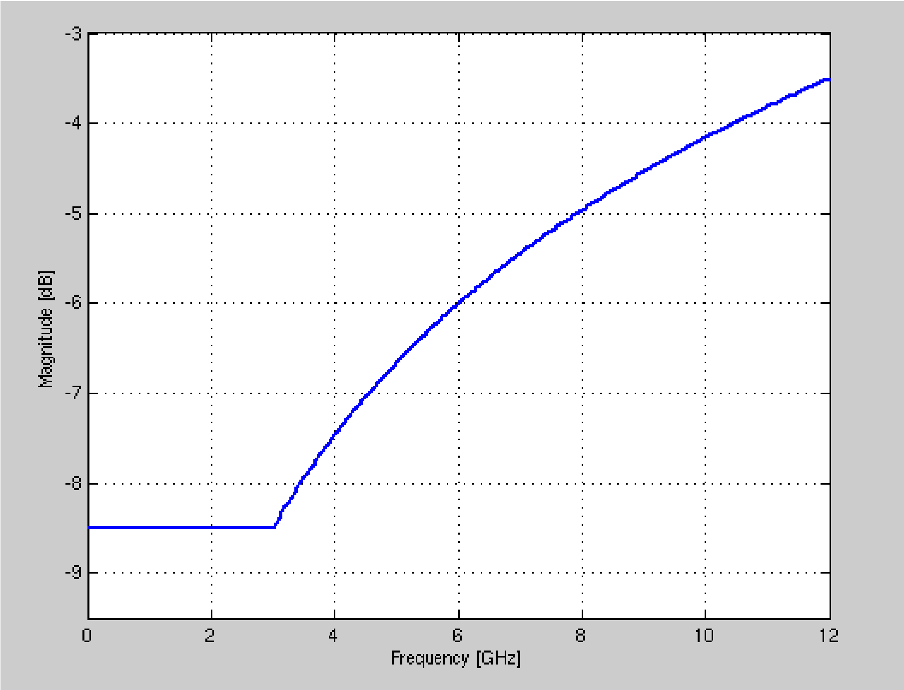
3.5.1 Transmitter Differential Return Loss

3.5.1.1 Reference

RL_DIFF - USB4 Specification Table 3-14

3.5.1.2 Requirement

$$\mathrm{SDD11(f)} = \begin{cases} -8.5 & 0.05 < f_{GHz} \le 3 \\ -3.5 + 8.3 \cdot \log 10\left(\frac{f_{GHz}}{12}\right) & 3 < f_{GHz} \le 12 \end{cases}$$



3.5.1.3 Test Objective

Confirm that the Differential Return loss falls within the limits of the USB4 Specification.

3.5.1.4 Test Method

1. Choose a supported USB4 speed to start with.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. Setup the Network Analyzer with measurement:

   Note: As the extra loss and distortion elements may be compensated by physical or mathematical means, use gating option to compensate for the parts of the fixture that are with 100ohm impedance. No de-embedding or gating to the mated USB Type-C connector or the TF traces.

- Frequency range of 50MHz to 12GHz
- IF BW of 1KHz
- At least 1600 points
- Impedance 85 ohm differential
- Define the Topology to Bal
- Define the measurement at SDD11.

4. Calibrate the network analyzer and test cables using a 2-port auto calibration kit.
5. Connect Lane under test TX_P, TX_N to the Network Analyzer.
6. Connect TX Lane that is not under test to 50ohm termination.

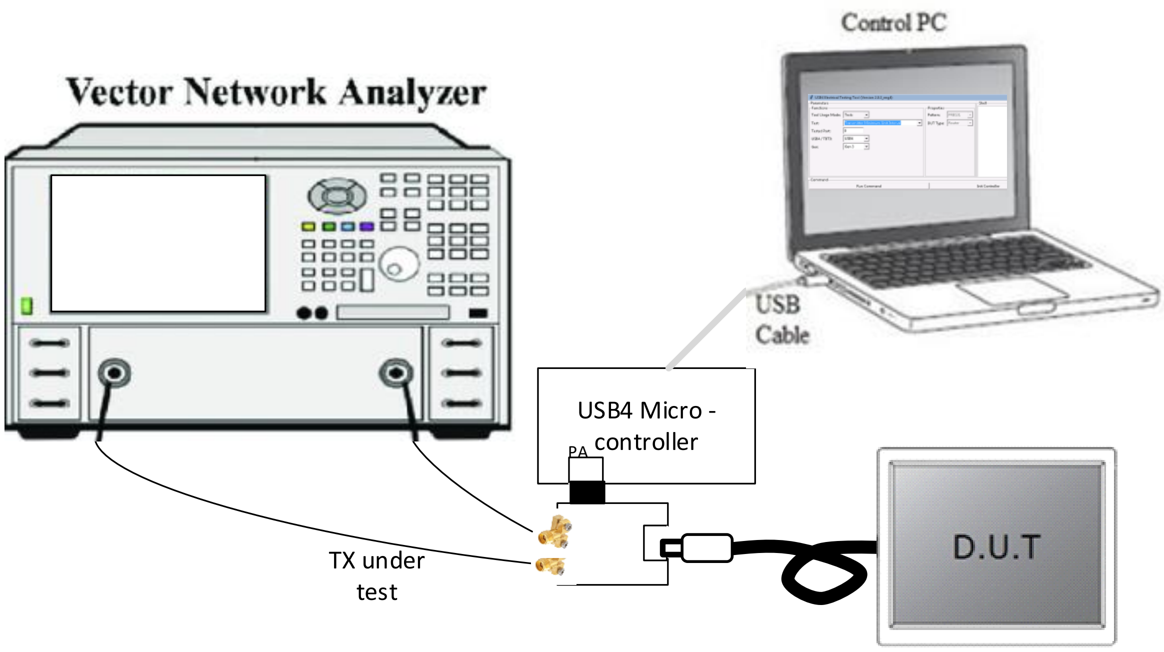


Figure 3. Transmitter Return Loss Test Setup

7. Measure the Differential R. Loss with the Network Analyzer
8. If Differential Return loss violated the above requirement, then **Fail**
9. Repeat the test for all remaining USB4 lanes.
10. Repeat the test for all supported USB4 Gen2 and Gen3 speeds.

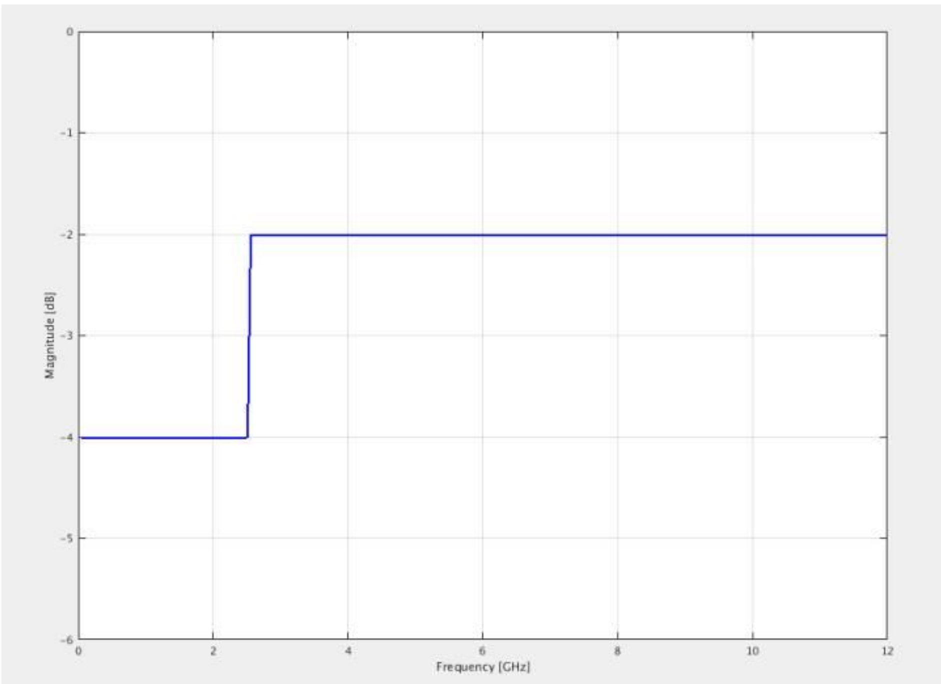
3.5.2 Transmitter Common Mode Return Loss

3.5.2.1 Reference

RL_COMM - USB4 Specification Table 3-14.

3.5.2.2 Requirement

$$\text{SCC11(f)} = \begin{cases} -4 & 0.05 < f_{GHz} \leq 2.5 \\ -2 & 2.5 < f_{GHz} \leq 12 \end{cases}$$



3.5.2.3 Test Objective

Confirm that the Common Mode Return loss falls within the limits of the USB4 Specification.

3.5.2.4 Test Method

1. Choose a supported USB4 speed to start with.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. Setup the Network Analyzer with measurement:

Note: As the extra loss and distortion elements may be compensated by physical or mathematical means, use gating option to compensate for the parts of the fixture that are with 100ohm impedance. No de-embedding or gating to the mated USB Type-C connector or the TF traces.

- *Frequency range of 50MHz to 12GHz*
- *IF BW of 1KHz*
- *At least 1600 points*

- *Impedance 85 ohm differential*
- *Define the Topology to Bal*
- *Define the measurement at SCC11.*

4. Calibrate the network analyzer and test cables using a 2-port auto calibration kit.
5. Connect Lane under test TX_P, TX_N to the Network Analyzer.
6. Measure the Common Mode R. Loss with the Network Analyzer.
7. If Common Mode Return loss violated the above requirement, then **Fail**.
8. Repeat the test for all remaining USB4 lanes.
9. Repeat the test for all supported USB4 Gen2 and Gen3 speeds.

4 Captive Device Receiver Testing

This section describes the tests required to verify whether the USB4 Receiver is compliant with the USB4 Specification.

The following sections provide detailed information on the setup and testing of the USB4 parameters. In the event of a discrepancy, the USB4 Specification prevails.

- Captive Device receiver compliance testing is defined at the output of a USB Type-C plug, at TP2 reference point.
- Calibration should be applied in cases where direct measurement is not feasible.
- All jitter measurements is done on the average frequency.
- As written in the Introduction – all post processing for RX calibration stressed eye and RX Signal Frequency Variations profile is done using the USB4 SigTest.

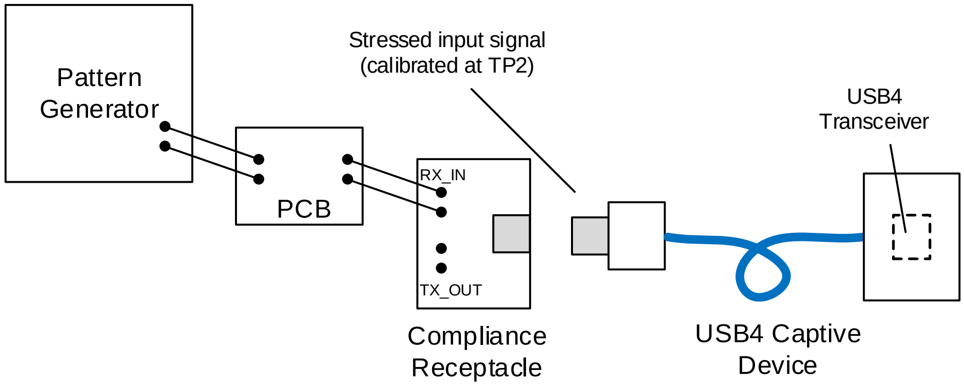


Figure 4. USB4 RX Compliance Points Definition

The ability of a Captive Device input to tolerate the worst-case incoming signal (referenced to TP2) is examined using a stressed receiver test. A Captive Device receiver shall operate at BER of 1E-12 or lower without forward-error-correction nor pre-coding applied when a stressed signal is driven at its input. Tolerance testing shall be performed with down-spreading of the clock enabled and while all ports are active.

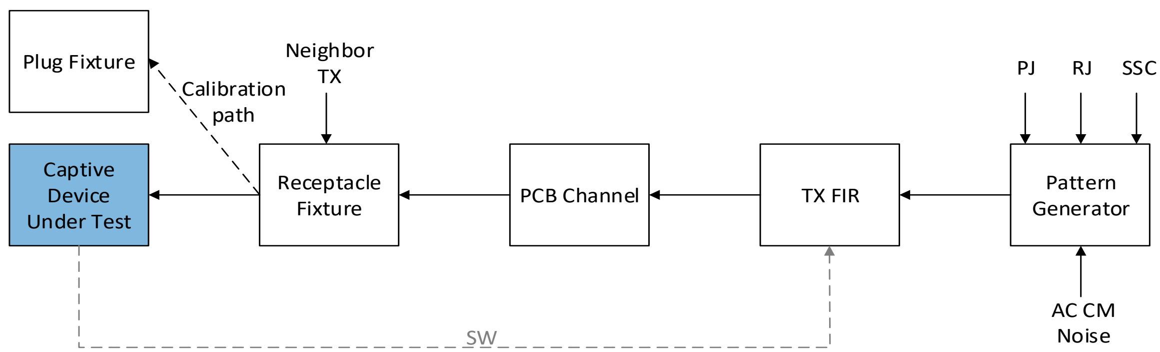


Figure 5. USB4 RX Tolerance Test Topologies

4.1 Receiver Test Setup

There are two physical setups required for Receiver testing, the Calibration Setup and the Test Setup.
Note: Before beginning any test or data acquisition, the BERT and Scope must be warmed, calibrated, and cables de-skewed.

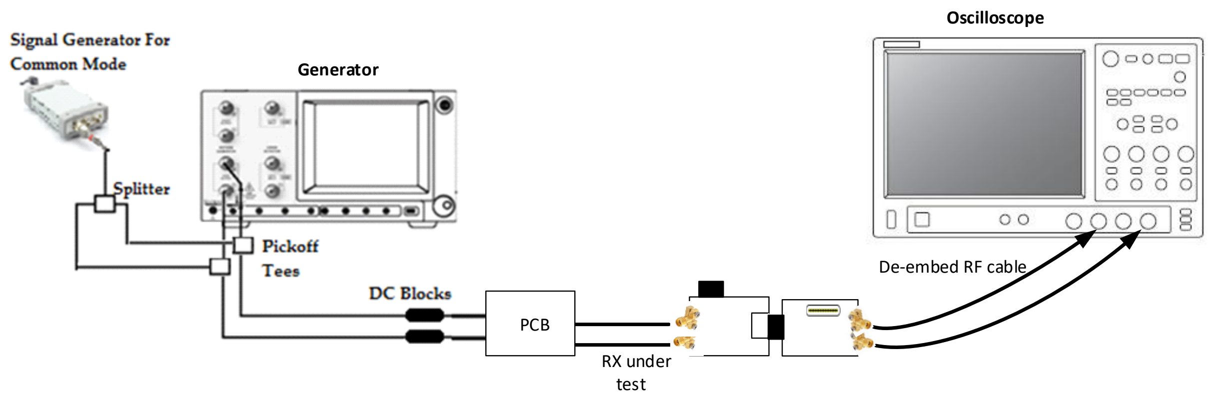


Figure 3. Receiver Calibration Setup – TP2

4.2 Receiver Stressed Eye Calibration

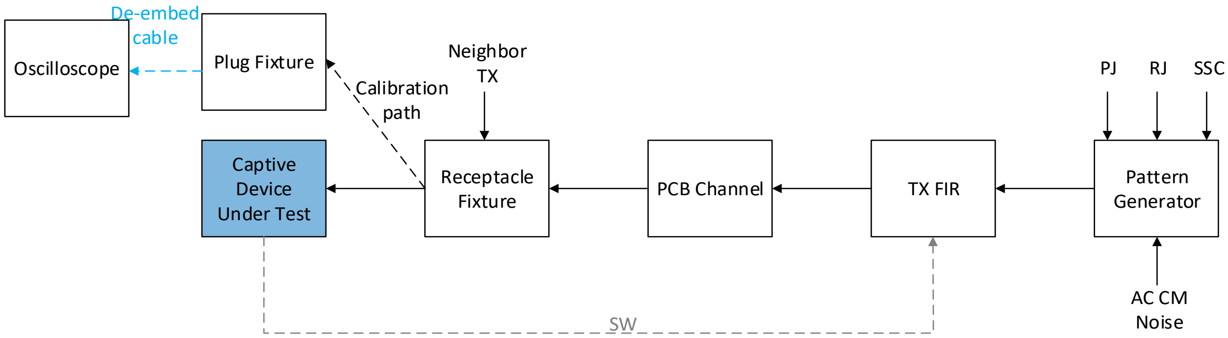
The USB4 Specification outlines a minimum Receiver Eye Diagram which is measured at the USB Type-C connector at the plug side. The RF cables from Plug Test Fixture to the scope should be de-embed.

The following procedure describes how to calibrate the USB4 minimum Receiver Eye Diagram.

Connect the test setup to the Scope as in Figure 6 above.

1. Connect the DATA+/DATA- Output of the BERT to Pickoff Tee.
2. Use splitter at the output of the signal generator and connect the splitter output to the Pickoff Tee.
3. Use phase matched cables to connect the Pickoff Tee sum out to DC blocks.
4. Connect pair of phase matched cables from the DC blocks to ISI channel and then to USB Type-C Receptacle and Plug connectors, with one more phase matched cable to oscilloscope. The last phased matched cables should be de-embed.

4.2.1 Stressed Electrical Signal for Gen2 TP2:



- Cables connecting from the last plug to the scope should be de-embedded.

Set the SSC on the pattern generator to be:

- SSC with modulation wave shape triangle
- Modulation frequency for Gen2 is 32KHz:
- Spread deviation from +300ppm up to -5300ppm

4.2.1.1 Data Dependent Jitter

4.2.1.1.1 Reference

USB4 Specification Table 3-18

4.2.1.1.2 Requirement

Data Dependent Jitter – 0.12UI p-p

4.2.1.1.3 Test Method

1. Choose a supported USB4 Gen2 speed.
2. Configure BERT transmit PRBS15 with SSC turned on and all jitter components turned off.
3. Configure BERT amplitude to fit into the Receiver Eye Mask.
4. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
5. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 40Mpts. The evaluated record length shall be 500µs per channel.
    - Pattern length -> Periodic
    - Jitter separation method shall be spectral.

- Adjust vertical scale to fit signal into scope screen.

6. Configure the BERT to preset 0
7. Measure DDJ and Register it.
8. Repeat the measurement for all 16 presets that are in Table 3-5 (reproduced above).
9. Configure the BERT to the preset that provides the lowest DDJ.
10. Make sure ISI Channel in the setup reach total DDJ of 0.12 +/-0.01UI p-p

4.2.1.2 AC Common Mode Measurements

4.2.1.2.1 Reference

AC_CM - USB4 Specification section 3.6.4

4.2.1.2.2 Requirement

AC common mode voltage - 100mVp-p

4.2.1.2.3 Test Method

1. Configure BERT transmit PRBS15 with SSC turned on and all jitter components turned off.
2. Configure Signal generator frequency to 400MHz, turn sinusoidal output on.
3. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5µs per channel.
    - Adjust vertical scale to fit signal into scope screen.
    - No CDR, no average and no interpolation to be used.
    - Scope BW should be as specified in 6.1

4. $V_{AC\text{-}CM}=(V_{TX\text{-}P}+V_{TX\text{-}N})/2$
5. Configure Signal generator amplitude to get $V_{AC\text{-}CM}$ of 100mVp-p
6. Turn off the ACCM noise before calibrating the RJ.

4.2.1.3 Random Jitter

4.2.1.3.1 Reference

RJ - USB4 Specification Table 3-18

4.2.1.3.2 Requirement

Random Jitter - 0.14UIp-p Referenced to 1E-12 statistics.

4.2.1.3.3 Test Method

1. Turn BERT RJ generator on (PRBS15) with SSC on.
2. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
3. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500µs per channel.
   - Pattern length -> Periodic
   - Jitter separation method shall be spectral
   - Adjust vertical scale to fit signal into scope screen.
   - Removing intrinsic scope noise and jitter is recommended.
4. Tune RJ in the BERT to reach 0.14UIp-p over the oscilloscope
5. Turn off the RJ noise before calibrating the PJ

4.2.1.4 Periodic Jitter

4.2.1.4.1 Reference

PJ - USB4 Specification Table 3-18

4.2.1.4.2 Requirement

Periodic Jitter - 0.17UIp-p.

4.2.1.4.3 Test Method

1. Turn BERT sinusoidal jitter (PJ) frequency to 1MHz generator on (PRBS15) with SSC on.
2. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
3. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500µs per channel.
   - Pattern length -> Periodic
   - Jitter separation method shall be spectral
   - Adjust vertical scale to fit signal into scope screen.

- Removing intrinsic scope noise and jitter is recommended

4. Tune PJ in the BERT to reach 0.17UIp-p

4.2.1.5 Total Jitter

4.2.1.5.1 Reference

TJ - USB4 Specification Table 3-18

4.2.1.5.2 Requirement

Total Jitter - 0.43UIp-p Referenced to BER = 1E-12 statistics.

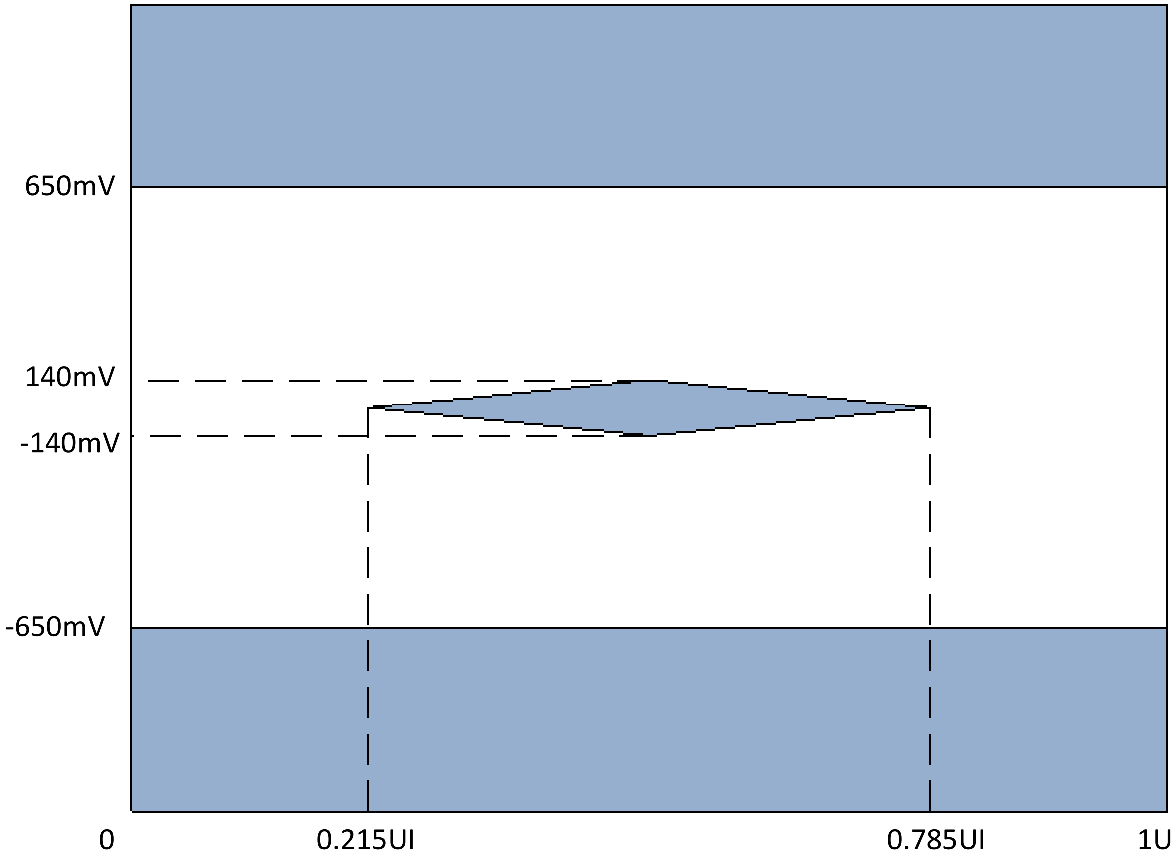
4.2.1.5.3 Test Method

1. Configure BERT transmit PRBS15 with SSC turned on and all jitter components turned on including the ACCM noise.
2. Measurement should be done with a reference CDR modeled by a 2^{nd} order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
3. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500µs per channel.
    - Pattern length -> Periodic
    - Jitter separation method shall be spectral
    - Adjust vertical scale to fit signal into scope screen.
    - Referenced to 1E-12 statistics.
    - Removing intrinsic scope noise and jitter is recommended.
4. Verify TJ of 0.43 ± 0.0125UIp-p for Gen2, if not, tune the total jitter by adjusting the RJ component for PJ frequencies 1MHz, 2MHz, 10 MHz and 50MHz and by adjusting the PJ component for frequency of 100MHz.

4.2.1.6 Input Eye Diagram

4.2.1.6.1 Reference

USB4 Specification Tables 3-17, 3-18



Gen2 Captive Device Input Eye Notation

4.2.1.6.2 Requirement

No Eye hits

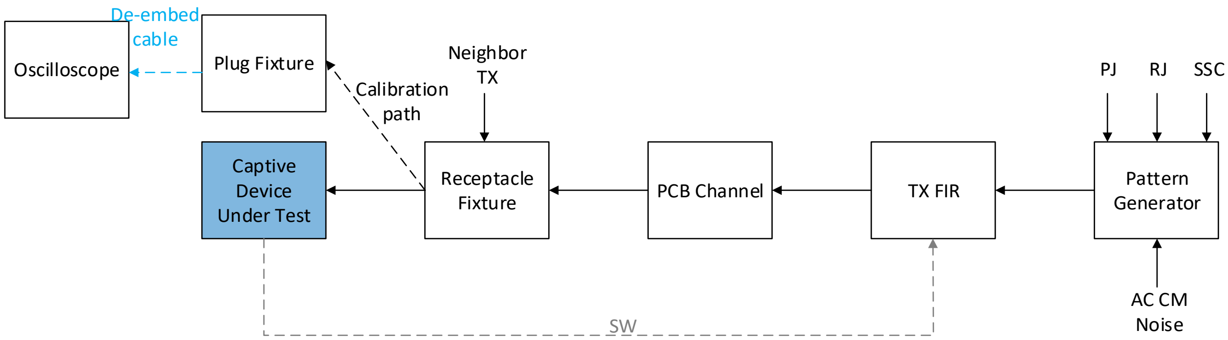
4.2.1.6.3 Test Method

1. Configure BERT transmit PRBS31 with SSC turned on and all jitter components turned on including the ACCM noise.
2. Measurement shall be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; interpolation shall be applied for obtaining effective sample rate of 1280GSa/s (e.g. X16 interpolation for 80GSa/s hardware sampling rate). Scope BW shall be as specified in Section 6.1.
3. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Adjust vertical and horizontal scale to fit signal into scope screen.
   - Measured 1E6 UI
4. Compare the data eye to the above eye diagram mask:

   i. If any part of the waveform hits the mask or if the eye is not minimal, Tune the BERT amplitude.

5. If Amplitude tune was needed, check all jitter and noise components again.
6. Save setup for Gen2 speed TP2, min eye as **Test Case Gen2**.
7. Repeat the steps in 4.2.1.4 Periodic Jitter, 4.2.1.5 Total Jitter and 4.2.1.6 Input Eye Diagram above for all PJ frequencies: 1MHz, 2MHz, 10MHz, 50MHz and 100MHz.

4.2.2 Stressed Electrical Signal for Gen3 TP2:



- Cables connecting from the last plug to the scope should be de-embedded.

Set the SSC on the pattern generator to be:
- SSC with modulation wave shape triangle
- Modulation frequency for Gen3 is 32KHz:
- Spread deviation from +300ppm up to -5300ppm

4.2.2.1 Data Dependent Jitter

4.2.2.1.1 Reference
USB4 Specification Table 3-19

4.2.2.1.2 Requirement
Data Dependent Jitter – 0.15UI p-p

4.2.2.1.3 Test Method
1. Choose a supported USB4 Gen3 speed.
2. Configure BERT transmit PRBS15 with SSC turned on and all jitter components turned off.
3. Configure BERT amplitude to fit into the Receiver Eye Mask.
4. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
5. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 40Mpts. The evaluated record length shall be 500μs per channel.
   - Pattern length -> Periodic

- Jitter separation method shall be spectral.
- Adjust vertical scale to fit signal into scope screen.

6. Configure the BERT to preset 0
7. Measure DDJ and Register it.
8. Repeat the measurement for all 16 presets that are in Table 3-5 (reproduced above).
9. Configure the BERT to the preset that provides the lowest DDJ.
10. Make sure ISI Channel in the setup reach total DDJ of 0.15 +/-0.01UI p-p

4.2.2.2 AC Common Mode Measurements

4.2.2.2.1 Reference

AC_CM - USB4 Specification section 3.6.4

4.2.2.2.2 Requirement

AC common mode voltage - 100mVp-p

4.2.2.2.3 Test Method

1. Configure BERT transmit PRBS15 with SSC turned on and all jitter components turned off.
2. Configure Signal generator frequency to 400MHz, turn sinusoidal output on.
3. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 27Mpts. The evaluated record length shall be 337.5μs per channel.
    - Adjust vertical scale to fit signal into scope screen.
    - No CDR, no average and no interpolation to be used.
    - Scope BW should be as specified in A.1

4. $V_{AC\text{-}CM}=(V_{TX\text{-}P}+V_{TX\text{-}N})/2$
5. Configure Signal generator amplitude to get $V_{AC\text{-}CM}$ of 100mVp-p
6. Turn off the ACCM noise before calibrating the RJ.

4.2.2.3 Random Jitter

4.2.2.3.1 Reference

RJ - USB4 Specification Table 3-19

4.2.2.3.2 Requirement

Random Jitter - 0.14UIp-p Referenced to 1E-12 statistics.

4.2.2.3.3 Test Method

1. Turn BERT RJ generator on (PRBS15) with SSC on.
2. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
3. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 40Mpts. The evaluated record length shall be 500µs per channel.
   - Pattern length -> Periodic
   - Jitter separation method shall be spectral.
   - Adjust vertical scale to fit signal into scope screen.
   - Removing intrinsic scope noise and jitter is recommended.
4. Tune RJ in the BERT to reach 0.14UIp-p over the oscilloscope
5. Turn off the RJ noise before calibrating the PJ

4.2.2.4 Periodic Jitter

4.2.2.4.1 Reference

PJ - USB4 Specification Table 3-19

4.2.2.4.2 Requirement

Periodic Jitter - 0.17UIp-p.

4.2.2.4.3 Test Method

1. Turn BERT sinusoidal jitter (PJ) frequency to 1MHz generator on (PRBS15) with SSC on.
2. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in A.1.
3. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ration to 40Mpts. The evaluated record length shall be 500µs per channel.
   - Pattern length -> Periodic
   - Jitter separation method shall be spectral.
   - Adjust vertical scale to fit signal into scope screen.

- Removing intrinsic scope noise and jitter is recommended.
-

4. Tune PJ in the BERT to reach 0.17UIp-p

4.2.2.5 Total Jitter

4.2.2.5.1 Reference

TJ - USB4 Specification Table 3-19

4.2.2.5.2 Requirement

Total Jitter - 0.46UIp-p Referenced to BER = 1E-12 statistics.

4.2.2.5.3 Test Method

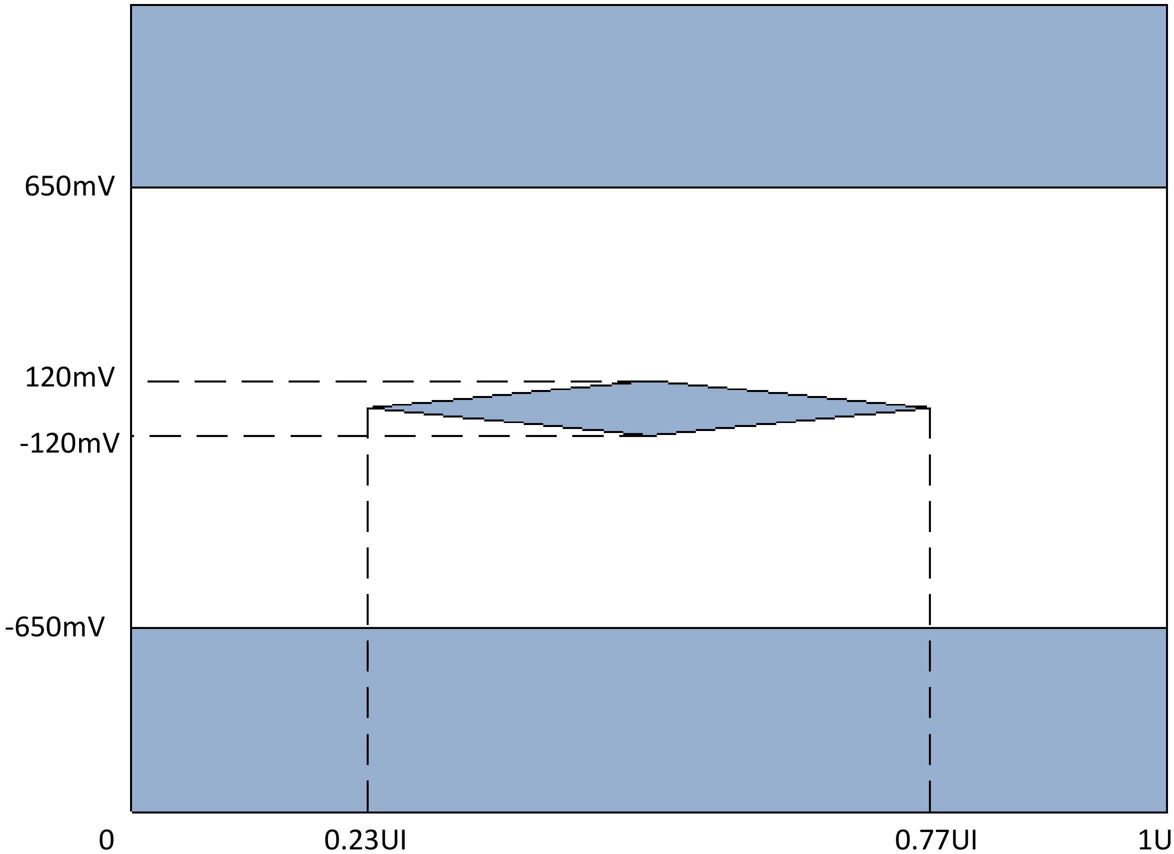
1. Configure BERT transmit PRBS15 with SSC turned on and all jitter components turned on including the ACCM noise.
2. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
3. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500µs per channel.
   - Pattern length -> Periodic
   - Jitter separation method shall be spectral
   - Adjust vertical scale to fit signal into scope screen.
   - Referenced to 1E-12 statistics.
   - Removing intrinsic scope noise and jitter is recommended.

4. Verify TJ of 0.46 ± 0.025UIp-p for Gen3, if not, tune the total jitter by adjusting the RJ component for PJ frequencies 1MHz, 2MHz, 10 MHz and 50MHz and by adjusting the PJ component for frequency of 100MHz.

4.2.2.6 Input Eye Diagram

4.2.2.6.1 Reference

USB4 Specification Tables 3-17, 3-19



Gen3 Captive Device Input Eye Notation

4.2.2.6.2 Requirement

No Eye hits

4.2.2.6.3 Test Method

1. Configure BERT transmit PRBS31 with SSC turned on and all jitter components turned on including the ACCM noise.
2. Measurement should be done with a reference CDR modeled by a 2^{nd} order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; interpolation shall be applied for obtaining effective sample rate of 1280GSa/s (e.g. X16 interpolation for 80GSa/s hardware sampling rate). Scope BW shall be as specified in Section 6.1.
3. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s
   - Adjust vertical and horizontal scale to fit signal into scope screen.
   - Measured 1E6 UI
4. Compare the data eye to the above eye diagram mask:

   i. If any part of the waveform hits the mask or if the eye is not minimal, Tune the BERT amplitude.

5. If Amplitude tune was needed, check all jitter and noise components again.
6. Save setup for Gen3 speed TP2, min eye as **Test Case Gen3**.
7. Repeat the steps in 4.2.2.4 Periodic Jitter, 4.2.2.5 Total Jitter and 4.2.2.6 Input Eye Diagram above for all PJ frequencies: 1MHz, 2MHz, 10MHz, 50MHz and 100MHz.

4.3 Receiver BER Test Procedure

After calibrating the stressed eye as described in the previous section, follow the following procedure to test the Receiver which is done with an internal error detector.

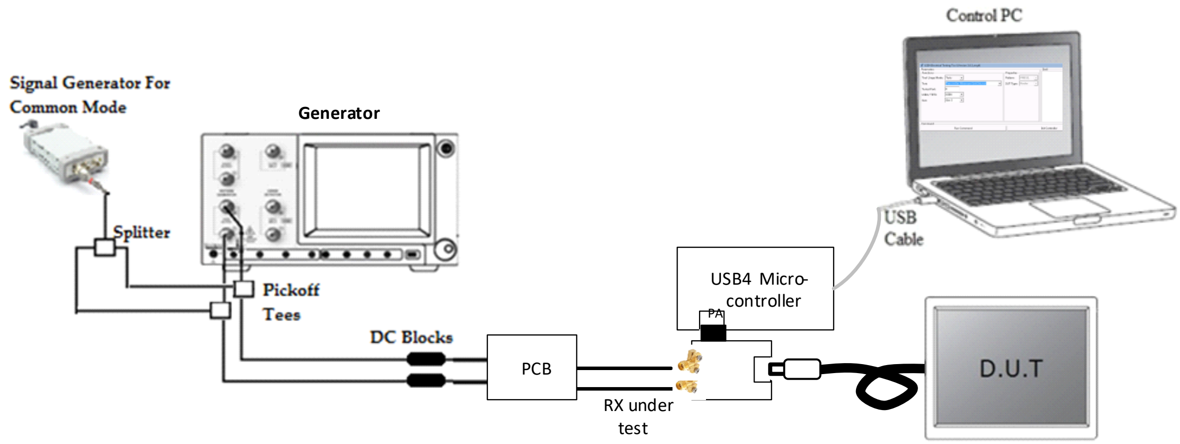


Figure 8. Receiver Test Setup at TP2

4.3.1 Gen2 BER at TP2

4.3.1.1 Reference

Refer to Figure 8 to connect the DUT for Receiver testing.

4.3.1.2 Test Method

- Plug the Receptacle test fixture into the DUT Plug.
  i. Connect the positive lane that was connected to the scope during calibration to Lane under test of the test fixture positive lane.
  ii. Connect the negative lane that was connected to the scope during calibration to Lane under test of the test fixture negative lane.
  iii. Connect the RX Lane that is not under test to USB4 Micro-Controller SMA lanes, 800mV amplitude to inject crosstalk.
  iv. Connect both TX Lanes to 50ohm termination.

1. Recall Test Case Gen2 calibrated setup that was saved in section 4.2.1.6.3.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. Initiate negotiation with the preset chosen in calibration.
4. Change the preset in the BERT according to the newly requested preset.
5. Configure DUT for the next negotiation step with the new preset.
6. Change the preset in the BERT according to the newly requested preset.
7. Configure DUT for the next negotiation step with the new preset.

8. If needed, change the preset in the BERT according to the newly requested preset.
9. Run BER test.
10. Record error count for 10sec.
11. Repeat steps 1-9 three more times and record the error count for 10 secs for each cycle (you will have a Total error count of 4 cycles).
12. Repeat steps 1 -9 above again and then:
13. Record the error count for Gen2 400sec
14. Verify the error count.
15. If the error count = 0 then **Pass**.
16. If error count > 0 then run steps 1 – 9 and then:
17. Record error count for Gen2 700sec
18. If error count > 1 then **Fail**
19. Repeat all the steps above for each PJ: 1MHz, 2MHz, 10MHz, 50MHz and 100MHz.
20. Repeat all the steps above for each Lane (each lane must be tested using each PJ frequency).

4.3.2 Gen3 BER at TP2

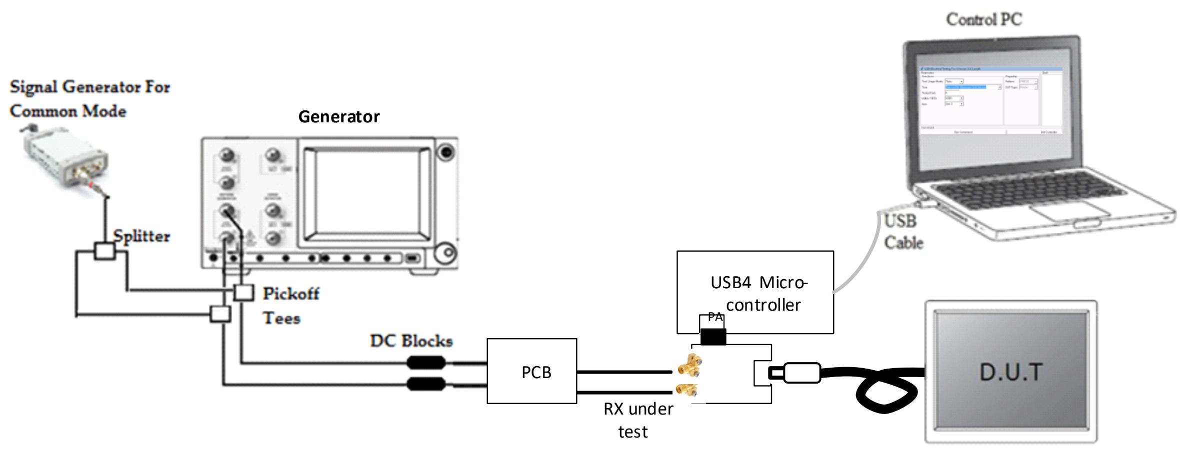


Figure 9. Receiver Test Setup at TP2

4.3.2.1 Reference

Refer to Figure 9 to connect the DUT for Receiver testing.

4.3.2.2 Test Method

- Plug the Receptacle test fixture into the DUT Plug.
- Connect the positive lane that was connected to the scope during calibration to Lane under test of the test fixture positive lane.
- Connect the negative lane that was connected to the scope during calibration to Lane under test of the test fixture negative lane.
- Connect the RX Lane that is not under test to USB4 Micro-Controller SMA lanes, 800mV amplitude to inject crosstalk.
- Connect both TX Lanes to 50ohm termination.

1. Recall Test Case Gen3 calibrated setup that was saved in section 4.2.2.6.3.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. Initiate negotiation with the preset chosen in calibration.
4. Change the preset in the BERT according to the newly requested preset.
5. Configure DUT for the next negotiation step with the new preset.
6. Change the preset in the BERT according to the newly requested preset.
7. Configure DUT for the next negotiation step with the new preset.
8. If needed, change the preset in the BERT according to the newly requested preset.
9. Run BER test.

10. Record the error count for 10sec
11. Repeat steps 1-9 three more times and record the error count for 10 secs for each cycle (you will have a Total error count of 4 cycles).
12. Repeat steps 1 -9 above again and then:
13. Record the error count for Gen3 200sec
14. Verify the error count.
15. If count = 0 then **Pass**.
16. If error count > 0 then run steps 1 – 9 and then:
17. Record the error count for Gen3 350sec
18. If error count > 1 then **Fail**
19. Repeat all the steps above for each PJ: 1MHz, 2MHz, 10MHz, 50MHz and 100MHz.
20. Repeat all the steps above for each Lane (each lane must be tested using each PJ frequency).

4.4 Receiver Multi Error-Burst Test

4.4.1 Multi Error-Burst Gen3

TBD

4.5 Receiver Signal Frequency Variations Training Test

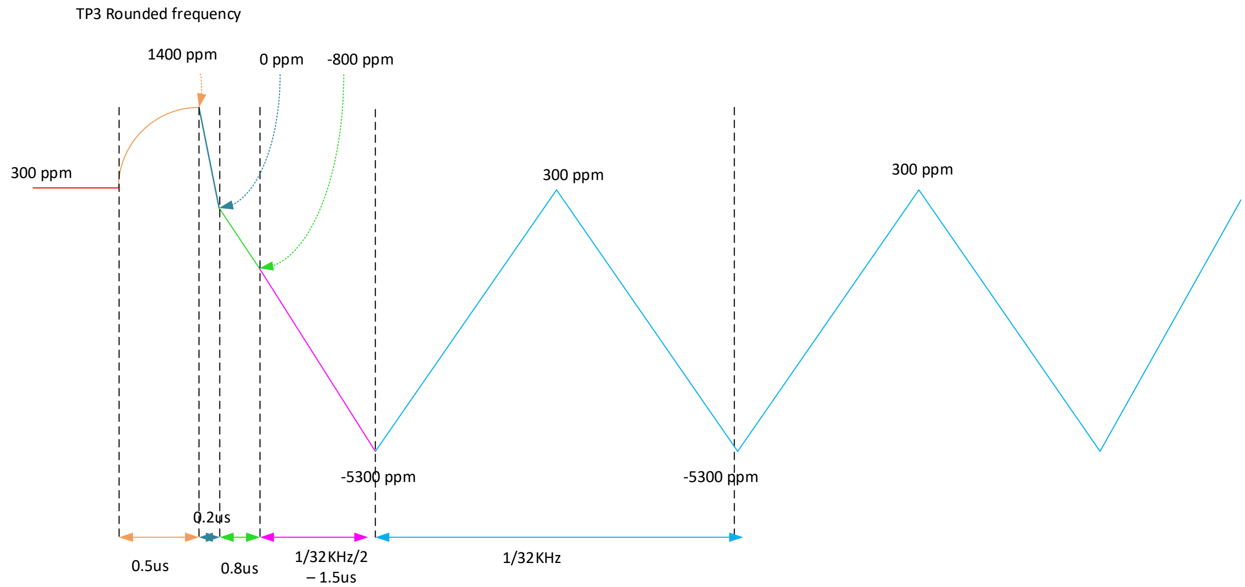
Note – in case the DUT is passing with the method described in CTS rev1.0, then the following test method is informative.

4.5.1 Signal Frequency Variations calibration for TP2:

4.5.1.1 Calibration Method

1. Connect the setup as showing in Figure 8 and follow section 4.1 and 4.2
2. Choose a supported USB4 speed to start with.
3. Recall Test Case 1 calibrated setup for PJ 100MHz that was saved in Section 4.2.1.6.3/4.2.2.6.3.
4. Configure Generator transmit PRBS15.
5. Turn off Generator periodic SSC modulation as saved in the recalled setup. Turn on and tune the clk-switch SSC modulation profile to be as in the following figure. All

other ingredients stay the same.



6. Capture the waveform and process it with the oscilloscope:
   - Sampling Rate ≥ 80GSa/s.
   - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500μs per channel.
   - Adjust vertical scale to fit signal into scope screen.
7. Extracted while applying a 2nd order low-pass filter with 3dB point at 5MHz over the signal phase.
8. Low frequency jitter variations shall be filtered out by averaging the extracted frequency variation waveform.
9. Save setup for the chosen speed TP2, as **Captive RX clk-switch.**
10. Repeat the calibration for all supported USB4 Gen2 and Gen3 speeds.

4.5.2 Signal Frequency Variations Training Gen2 and Gen3 for TP2

4.5.2.1 Reference

USB4 Specification table 3-17.

4.5.2.2 Requirement

The probability for BER shall be 1E−6 or less.

4.5.2.3 Test Objective

Confirm that the Receiver don’t lose lock and record errors when frequency variation is applied.

4.5.2.4 Test Method

1. Use the same test setup as in Figure 8
2. Choose a supported USB4 speed to start with.

3. Recall **Captive RX clk-switch** calibrated setup for PJ 100MHz that was saved in Section 4.5.1.1.
4. Turn off Generator special SSC modulation as saved in the recalled setup.
5. Configure DUT transmitter to output PRBS31 on all lanes.
6. Initiate negotiation with the preset 0.
7. Change the preset in the Generator according to the newly requested preset.
8. Configure DUT for the next negotiation step with the new preset.
9. Change the preset in the Generator according to the newly requested preset.
10. Configure DUT for the next negotiation step with the new preset.
11. If needed, change the preset in the Generator according to the newly requested preset.
12. Run BER test. The ETT will pop-up a window asking, "to turn on clk-switch over the Generator". Before clicking OK, turn on the special SSC profile over the Generator. Note – after enabling the special SSC profile, click immediately OK over the ETT.
13. Record Error Count for 10sec.
14. If BER ≤ 1E-6 then **Pass**.
15. If BER> 1E-6 then **Fail**.
16. Repeat all the steps above for each Lane 20 times.
17. Repeat the test above for all supported USB4 Gen2 and Gen3 speeds.

4.6 Receiver Return Loss Gen2 and Gen3

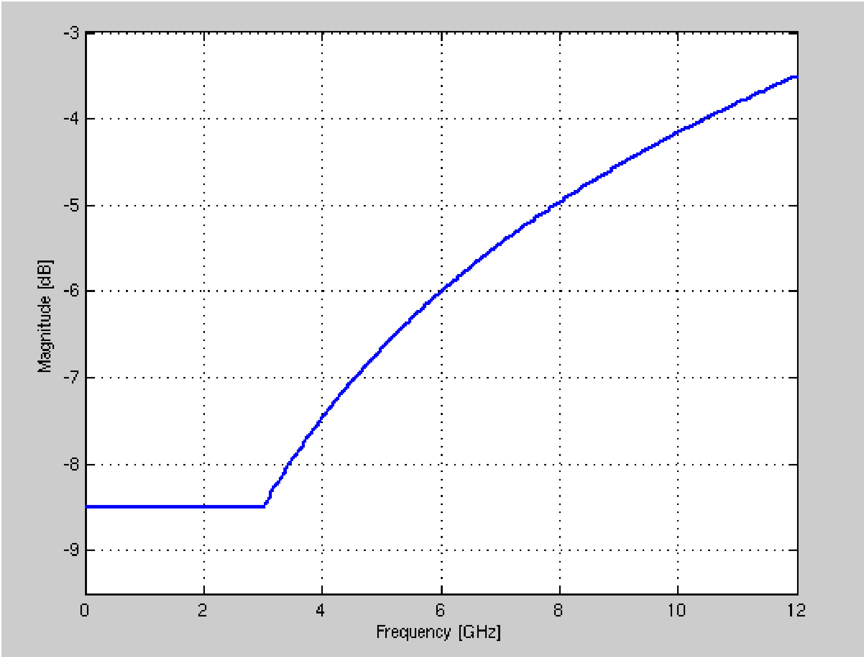
4.6.1 Receiver Differential Return Loss

4.6.1.1 Reference

USB4 Specification Table 3-17

4.6.1.2 Requirement

$$\mathrm{SDD22(f)} = \begin{cases} -8.5 & 0.05 < f_{GHz} \leq 3 \\ -3.5 + 8.3 \cdot \log 10\left(\frac{f_{GHz}}{12}\right) & 3 < f_{GHz} \leq 12 \end{cases}$$



4.6.1.3 Test Objective

Confirm that the Differential Return loss falls within the limits of the USB4 Specification.

4.6.1.4 Test Method

1. Create s4p files, for all lanes that measuring USB Type-C plug and receptacle test fixture together. This file should be de-embed in the setup.
2. Choose a supported USB4 speed to start with.
3. Configure DUT transmitter to output PRBS31 and enable RX on all lanes with SSC turned on.
4. Setup the Network Analyzer with measurement:

   Note: Since RL is defined over TP2. Apply de-embedding s4p file that was measured over step #1.
   - Frequency range of 50MHz to 12GHz
   - IF BW of 1KHz
   - At least 1600 points
   - Impedance 85-ohm differential
   - Add the s4p measured at #1, USB Type-C plug and receptacle test fixture de-embedding.
   - Define the Topology to Bal
   - Define the measurement at SDD22.
5. Calibrate the network analyzer using a 2-port auto calibration kit
6. Connect both USB4 TX ports to 50ohm termination.

7. Connect Lane under test RX_P, RX_N to the Network Analyzer

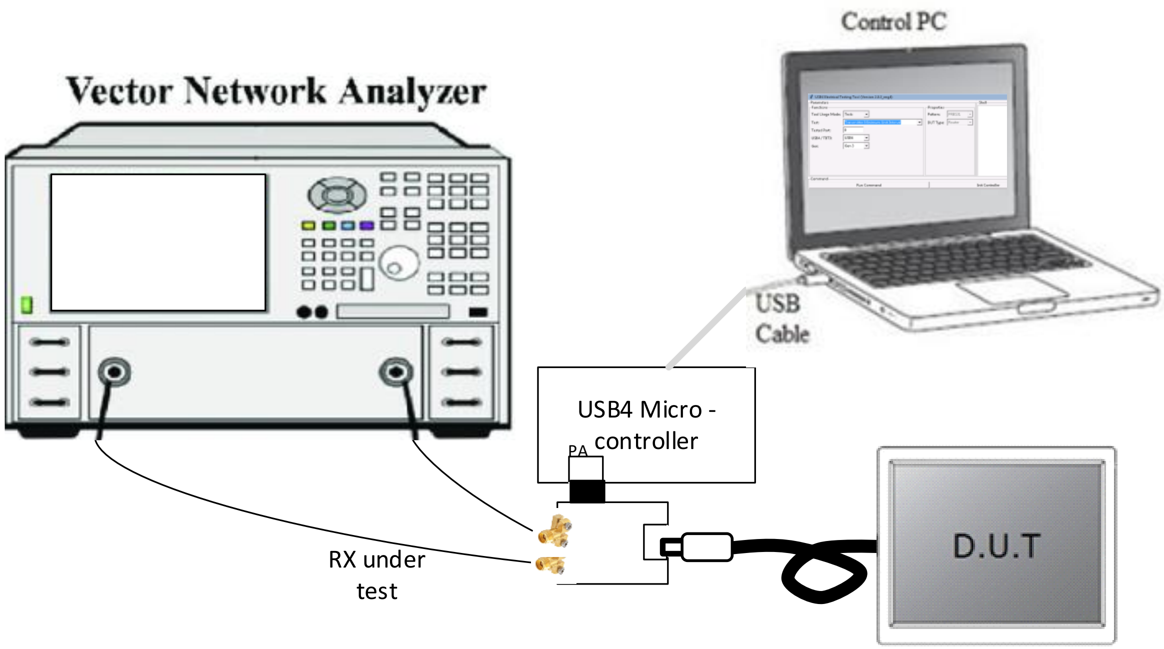


Figure 10. Receiver Return Loss Test Setup

8. Measure the Return Loss with the Network Analyzer.
9. If Return loss violated the above requirement, then **Fail**
10. Repeat the test for all remaining USB4 lane.
11. Repeat the test for all supported USB4 Gen2 and Gen3 speeds.

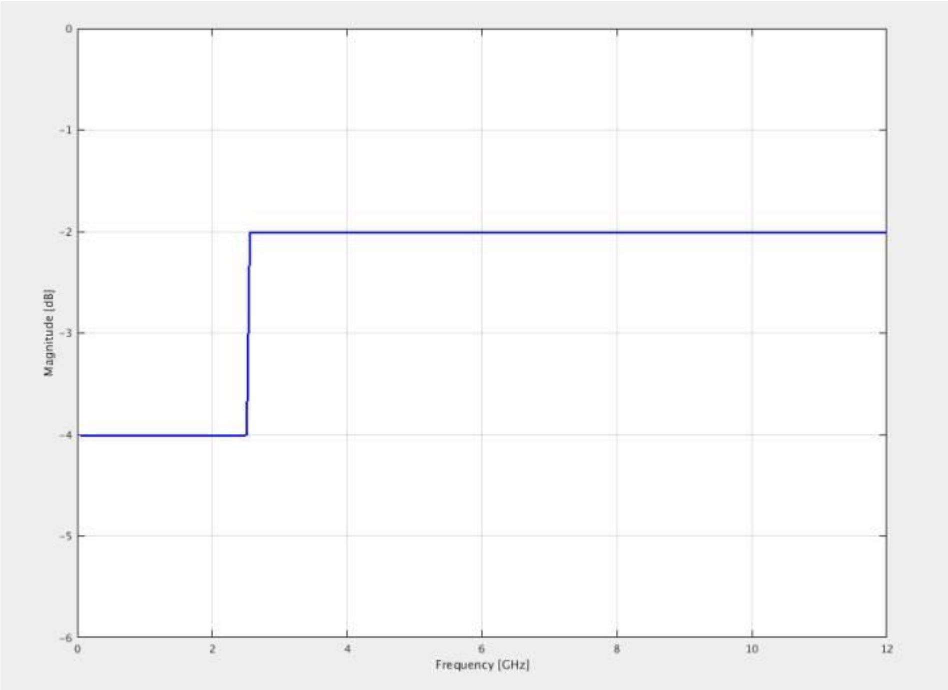
4.6.1 Receiver Common Mode Return Loss

4.6.1.1 Reference

RL_COMM - USB4 Specification Table 3-17.

4.6.1.2 Requirement

$$SCC22(f) = \begin{cases} -4 & 0.05 < f_{GHz} \leq 2.5 \\ -2 & 2.5 < f_{GHz} \leq 12 \end{cases}$$



4.6.1.3 Test Objective

Confirm that the Common Return loss falls within the limits of the USB4 Specification.

4.6.1.4 Test Method

1. Create s4p files, for all lanes that measuring USB Type-C plug and receptacle test fixture together. This file should be de-embed in the setup.
2. Choose a supported USB4 speed to start with.
3. Configure DUT transmitter to output PRBS31 and enable RX on all lanes with SSC turned on.
4. Setup the Network Analyzer with measurement:

   Note: Since RL is defined over TP2. Apply de-embedding s4p file that was measured over step #1.
   - Frequency range of 50MHz to 12GHz
   - IF BW of 1KHz
   - At least 1600 points
   - Impedance 85-ohm differential
   - Add the s4p measured at #1, USB Type-C plug and receptacle test fixture de-embedding.
   - Define the Topology to Bal
   - Define the measurement at SCC22.
5. Calibrate the network analyzer using a 2-port auto calibration kit
6. Connect both USB4 TX ports to 50ohm termination.

7. Connect Lane under test RX_P, RX_N to the Network Analyzer
8. Measure the Return Loss with the Network Analyzer.
9. If Return loss violated the above requirement, then **Fail**
10. Repeat the test for all remaining USB4 lane.
11. Repeat the test for all supported USB4 Gen2 and Gen3 speeds.

5 Captive Device Low speed signal Testing

The Low-Speed link is used for initial link configuration.
Low-Speed Link transactions are sent and received over the LSTX and LSRX wires.
The LSTX/LSRX lines are connected to SBU1/SBU2 on the USB Type-C connector after negotiation to the USB4 Alternate Mode has occurred. LSTX and LSRX are a UART interface which operates at a 1MHz baud rate. The local UART bus between Router Assembly and near cable end or Device and near cable end shall function when high speed USB4 traffic is present to enable debug and link training to work properly.
Figure 11 indicates the Low-Speed signals for a Captive Device.
All Captive Devices shall meet the Low-Speed Link requirements defined section 5.1.
Low-Speed signal parameters are defined at the connector.

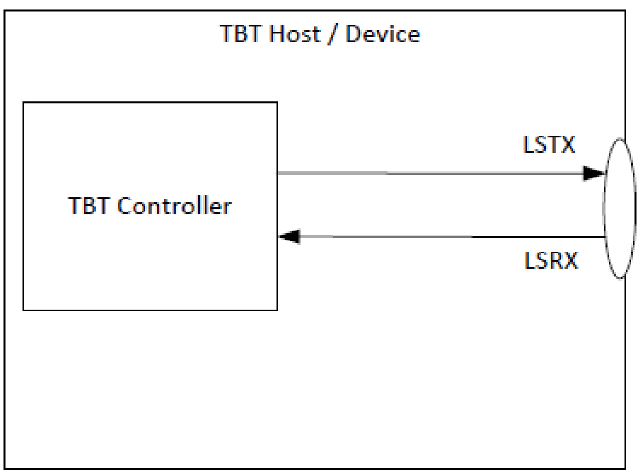


Figure 11 – Captive Device Low-Speed Signals

5.1 Captive Device LSTX and LSRX Specifications

Low Speed Signal testing should be done for each port in the DUT.
The LSTX, LSRX signals are going through SBU1, SBU2 pins over the USB Type-C connector.
For all setups the DUT should be connected via USB4 Test Fixture with USB4 u-controller in order to establish link.

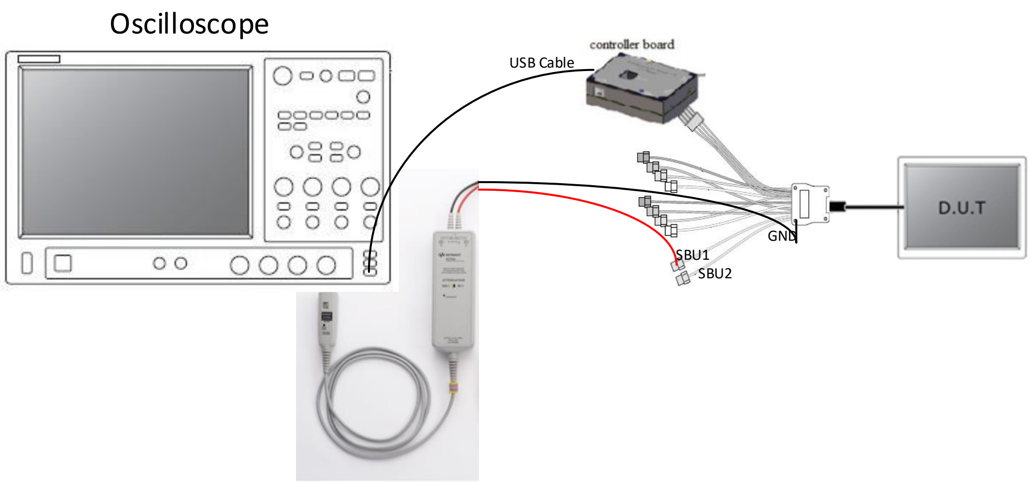


Figure 12 - Figure of low speed TX/RX signal testing using scope

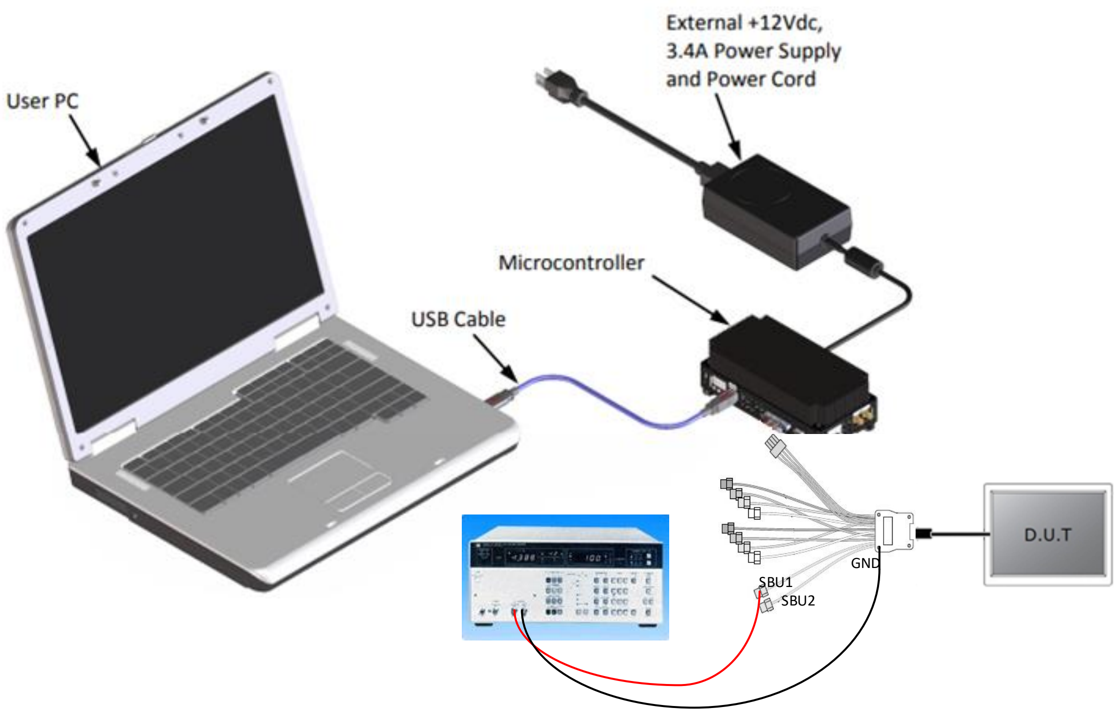


Figure 13 - Figure of low speed TX/RX signal testing using voltage meter

5.1.1 LSTX High Voltage Measurement

5.1.1.1 Reference

$LSTX_{VOH}$ - USB4 Specification Table 3-1

5.1.1.2 Requirement

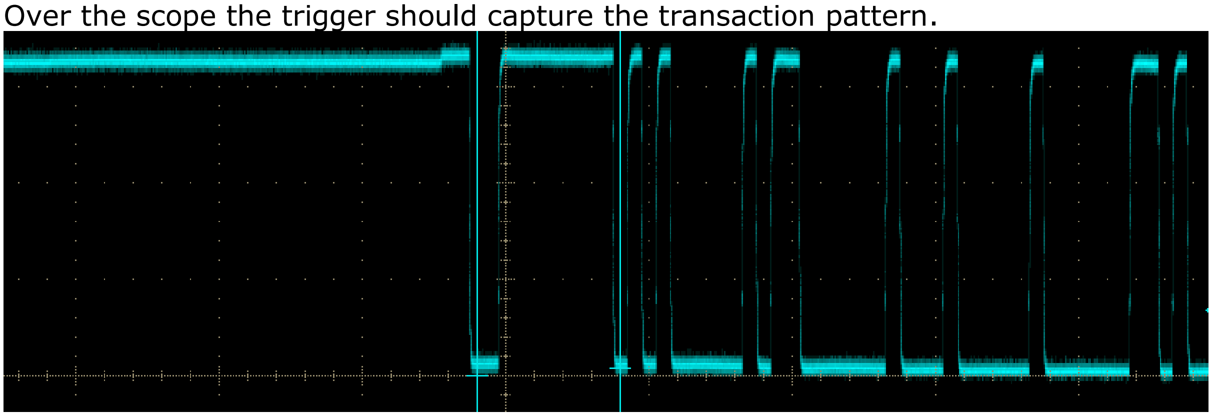
2.2V ≤ $LSTX_{VOH}$ ≤ 3.47V

5.1.1.3 Test Objective

Confirm that the parameter measured under all conditions does not exceed minimum or maximum limits of the specification

5.1.1.4 Test Method

1. Connect a voltage meter/fluke to SBU1 header in the USB4 Test Fixture (Figure 13).
2. Power up the DUT.
3. Measure the voltage.
4. If $LSTX_{VOH}$ < 2.2V or >3.47V then Fail.
5. Connect a scope with high impedance probe to the SBU1 header in the USB4 Test Fixture (Figure 12).
   - In the scope use a trigger based on pulse width, negative polarity, trigger when the pulse width <10us and threshold of 600mV.
   - Horizontal scale = 10us per square, vertical scale = 1V per square.
6. Power up the DUT.
7. Over the scope the trigger should capture the transaction pattern.



8. Measure the high/low value of the “1” amplitude for a bit inside the transaction.
9. If $LSTX_{VOH}$ < 2.2V or >3.47V then Fail.

5.1.2 LSTX Low Voltage Measurement

5.1.2.1 Reference

$LSTX_{VOL}$ - USB4 Specification Table 3-1

5.1.2.2 Requirement

$-0.2V \leq LSTX_{VOL} \leq 0.4V$

5.1.2.3 Test Objective

Confirm that the parameter measured under all conditions does not exceed minimum or maximum limits of the specification

5.1.2.4 Test Method

1. Connect a voltage meter/fluke to SBU1 header in the USB4 Test Fixture (Figure 13).
2. DUT should be in power down.
3. Measure the voltage.
4. If $LSTX_{VOL}$ < -0.2V or >0.4V then Fail.
5. Connect a scope with high impedance probe to the SBU1 header in the USB4 Test Fixture (Figure 12).
   - In the scope use a trigger based on pulse width, negative polarity, trigger when the pulse width <10us and threshold of 600mV.
   - Horizontal scale = 10us per square, vertical scale = 1V per square.
6. Power up the DUT
7. Over the scope the trigger should capture the transaction pattern.
8. If $LSTX_{VOL}$ < -0.2V or >0.4V then Fail.

5.1.3 LSTX Rise/Fall time Measurement

5.1.3.1 Reference

LSX_{TRTF} - USB4 Specification Table 3-1

5.1.3.2 Requirement

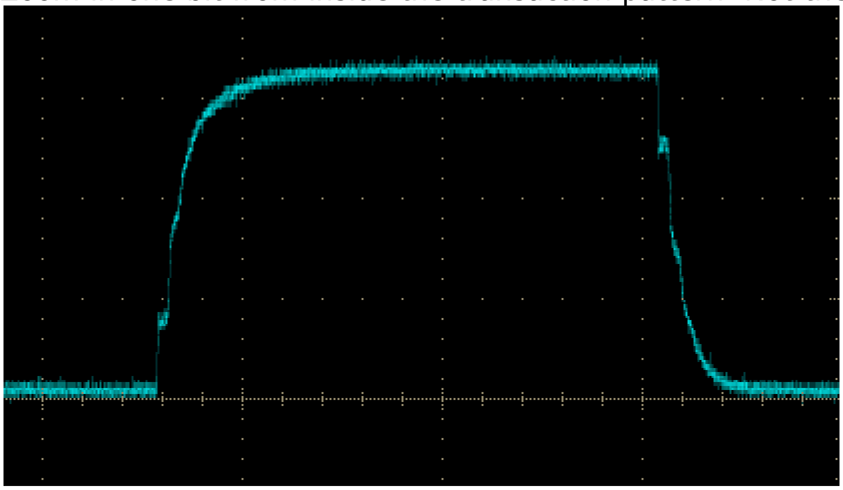
3.5ns ≤ LSX_{TRTF}

5.1.3.3 Test Objective

Confirm that the parameter measured under all conditions does not exceed minimum or maximum limits of the specification

5.1.3.4 Test Method

1. Connect the DUT via USB4 Test Fixture with USB4 u-controller in order to establish link.
2. The measurement should be in transaction only and not from power down to up (or the opposite).
3. Connect a scope with high impedance probe to the SBU1 header for LSTX test in the USB4 Test Fixture (Figure 12).
   - In the scope use a trigger based on pulse width, negative polarity, trigger when the pulse width <10us and threshold of 600mV.
   - Horizontal scale = 10us per square, vertical scale = 1V per square.
4. Power up the DUT
5. Over the scope the trigger should capture the transaction pattern.
6. Zoom in one bit from inside the transaction pattern. Not the 1st or the last bit.



7. Measure the rise and fall time (10%-90%) for LSTX.
8. If LSX_{TRTF} < 3.5ns then Fail.

5.1.4 LSX UI Duration Measurement

5.1.4.1 Reference

LSX_UI - USB4 Specification Table 3-1

5.1.4.2 Requirement

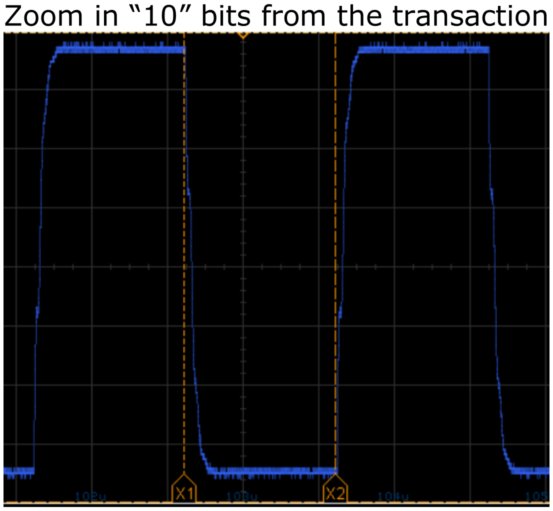
980ns ≤ LSX_UI ≤ 1020ns

5.1.4.3 Test Objective

Confirm that the parameter measured under all conditions does not exceed minimum or maximum limits of the specification

5.1.4.4 Test Method

1. Connect the DUT via USB4 Test Fixture with USB4 u-controller in order to establish link.
2. The measurement should be in transaction, over the transaction pattern.
3. Connect a scope with high impedance probe to the SBU1 header for LSTX in the USB4 Test Fixture (Figure 12).
4. In the scope use a trigger based on pulse width, negative polarity, trigger when the pulse width <10us and threshold of 600mV.
5. Horizontal scale = 10us per square, vertical scale = 1V per square.
6. Power up the DUT
7. Over the scope the trigger should capture the transaction pattern.
8. Zoom in “10” bits from the transaction pattern.



9. Measure the duration from falling edge of the “1” to the rising edge of “0”, named LSX_UI.
10. If LSX_UI < 980ns or >1020ns then Fail.

5.1.5 LSRX High Voltage Detection Measurement

5.1.5.1 Reference

$LSRX_{VIH}$ - USB4 Specification Table 3-1

5.1.5.2 Requirement

2.0V ≤ $LSRX_{VIH}$ ≤ 3.47V

5.1.5.3 Test Objective

Confirm that the DUT can detect the LTRX signal in the minimum limit of the specification

5.1.5.4 Test Method

1. Connect the DUT via USB4 Test Fixture with USB4 u-controller with external 3.3V power supply connected to the LSX input in order to establish link.

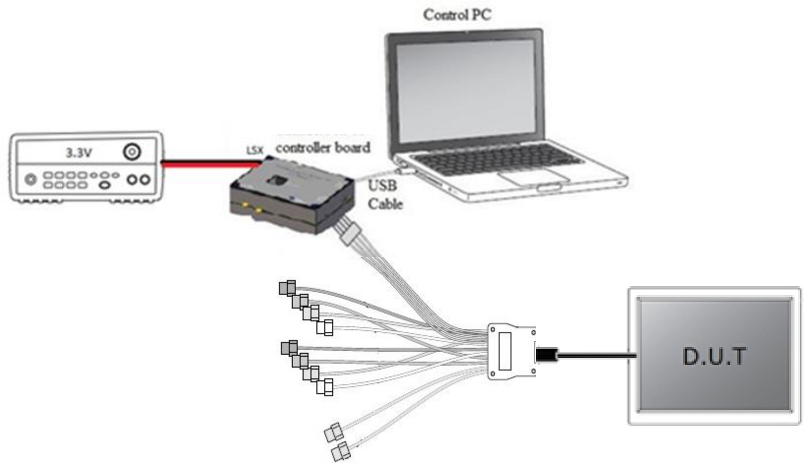


Figure 14 - Figure of low speed RX signal testing

2. Set the 3.3V power supply to 3.47V
3. Establish there is a link
4. Reduce the external power supply to 2.0V
5. If Link is lost, then Fail

5.1.6 LSRX Low Voltage Detection Measurement

5.1.6.1 Reference

$LSRX_{VIL}$ - USB4 Specification Table 3-1

5.1.6.2 Requirement

$-0.2V \leq LSRX_{VIL} \leq 0.5V$

5.1.6.3 Test Objective

Confirm that the DUT can detect the LTRX signal in the minimum limit of the specification

5.1.6.4 Test Method

1. Connect the DUT via USB4 Test Fixture with USB4 u-controller with external 3.3V power supply connected to the LSX input in order to establish link (Figure 14).
2. Set the 3.3V power supply to 3.3V
3. Establish there is a link
4. Reduce the external power supply to 0.5V
5. If Link is established, then Fail

6 Appendix A – Scope Configurations

6.1 Scope BW Limit

- Gen 2 Configuration: Scope BW should be 16 GHz.
- Gen 3 Configuration: Scope BW should be 21 GHz.

7 Appendix B – Equalization Calibration

When testing at TP3, a reference equalization must be applied on the Oscilloscope. The reference receiver equalization function is comprised of parametric Continuous-Time-Linear-Equalizer (CTLE) and Decision-Feedback-Equalizer (DFE), as described in USB4 Specification section 3.3.4.1 and Section 3.3.4.2 respectively.
A measurement that is referenced to TP3 shall use the best equalization parameters so that the calculated eye-diagram is optimized. Note – since USB4 SigTest is published, all that flow is done over USB4 SigTest.

7.1 Gen 2 Configuration

The following equation describes the frequency response for USB4 reference CTLE that shall be used with the following parameters:

$$H(s) = 1.41 \cdot w_{p2} \cdot \frac{s + \frac{A_{DC}}{1.41} \cdot w_{p1}}{(s + w_{p1}) \cdot (s + w_{p2})}$$

- $AC\ Gain\ =\ 1.41$
- $Wp1\ =\ 2 * \pi * 1.5G\ rad/sec$
- $Wp2\ =\ 2 * \pi * 5G\ rad/sec$
- A_{DC} is the DC gain, Ten different CTLE configurations shall be applied such that A_{DC} is one of $\left\{10^{\frac{-x}{20}} : x = 0 \div 9[dB]\right\}$ and should be calibrated as follows:

1. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
2. Chose A_{DC} for x=0
3. Apply automatic DFE with max of 50mV. Gain should be 1 at all time. Apply automatic DFE delay.
4. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
5. Capture the waveform and process it with the oscilloscope:
    a. Sampling Rate ≥ 80GSa/s
    b. Adjust vertical and horizontal scale to fit signal into scope screen.
    c. Measured 1E6 UI
6. Eye height should be at the "0" of the real time eye horizontal position. A Histogram should be applied to the lower and upper section of the eye, with +/-1% deviation in time axis in order to calculate the eye height. Use min value from upper histogram result and max value from lower histogram results. Eye height is the delta between them. See Figure 15 and Figure 16.
7. Capture 5 times (each time over new 1MUI record length) min value of both eye height and eye width.
8. Average the 5 captured values; average{5 times min eye height}, average{5 times min eye width}
9. Start over from step #2 with x=x+1 and till x=9.

- The chosen A_{DC} value including DFE tap value should be the one that gives the maximal eye height.
- If there are two A_{DC} values including DFE tap with the same eye height, choose the one with the greater eye width.

7.2 Gen 3 Configuration

The following equation describes the frequency response for USB4 reference CTLE that shall be used with the following parameters:

$$H(s) = 1.41 \cdot w_{p2} \cdot \frac{s + \frac{A_{DC}}{1.41} \cdot w_{p1}}{(s + w_{p1}) \cdot (s + w_{p2})}$$

- $AC\ Gain$: 1.41
- $Wp1 = 2 * \pi * 5G\ rad/sec$
- $Wp2 = 2 * \pi * 10G\ rad/sec$
- A_{DC} is the DC gain, Ten different CTLE configurations shall be applied such that A_{DC} is one of $\left\{10^{\frac{-x}{20}} : x = 0 \div 9[dB]\right\}$ and should be calibrated as follows:
  1. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
  2. Chose A_{DC} for x=0
  3. Apply automatic DFE with max of 50mV. Gain should be 1 at all time. Apply automatic DFE delay.
  4. Measurement should be done with a reference CDR modeled by a 2nd order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW should be as specified in 6.1.
  5. Capture the waveform and process it with the oscilloscope:
     a. Sampling Rate ≥ 80GSa/s
     b. Adjust vertical and horizontal scale to fit signal into scope screen.
     c. Measured 1E6 UI
  6. Eye height should be at the “0” of the real time eye horizontal position. A Histogram should be applied to the lower and upper section of the eye, with +/- 1% deviation in time axis in order to calculate the eye height. Use min value from upper histogram result and max value from lower histogram results. Eye height is the delta between them. See Figure 15 and Figure 16.
  7. Capture 5 times (each time over new 1MUI record length) min value of both eye height and eye width.
  8. Average the 5 captured values; average{5 times min eye height}, average{5 times min eye width}
  9. Start over from step #2 with x=x+1 and till x=9.
- The chosen A_{DC} value including DFE tap value should be the one that gives the maximal eye height.
- If there are two A_{DC} values including DFE tap with the same eye height, choose the one with the greater eye width.

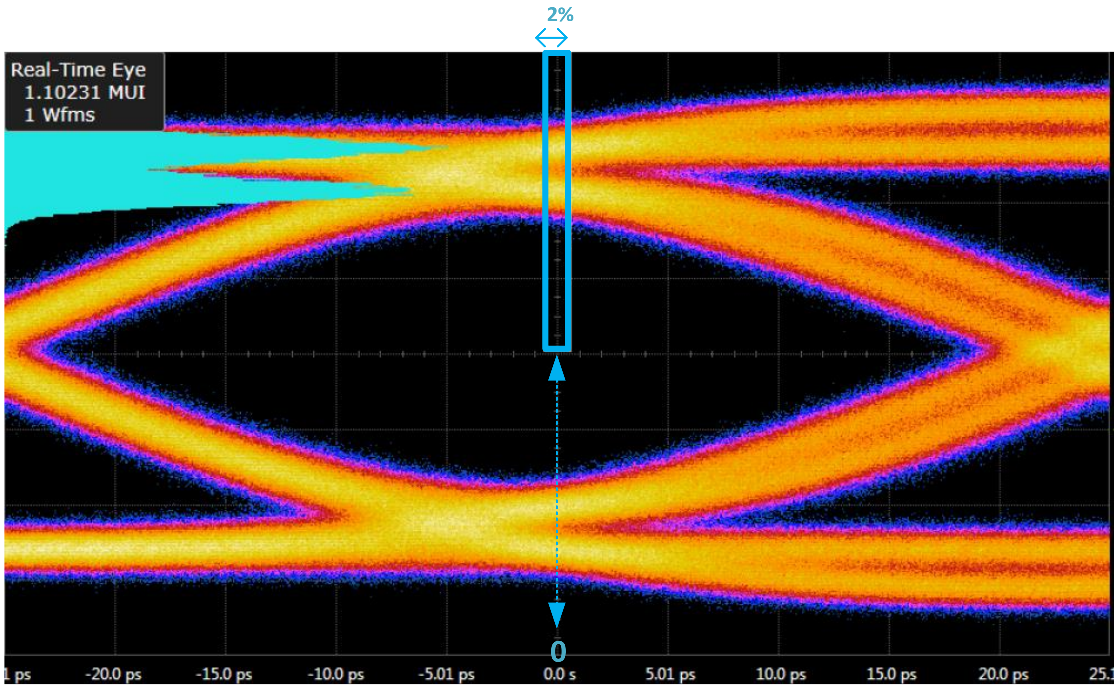


Figure 15. USB4 RX TP3 Eye Height upper location measurement

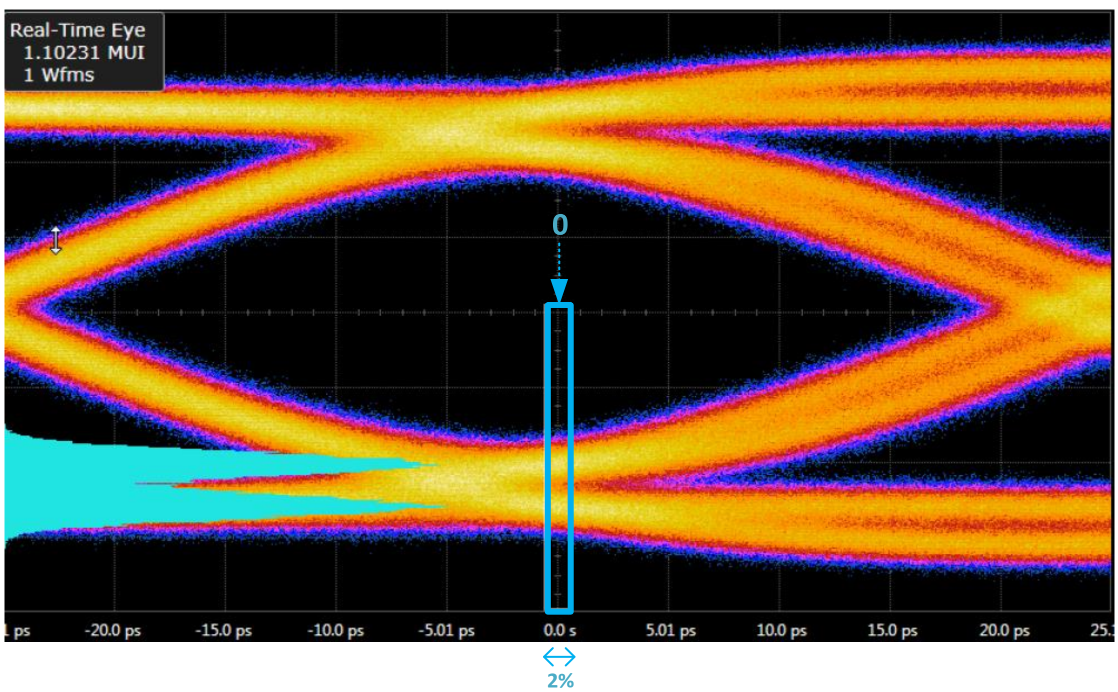


Figure 16. USB4 RX TP3 Eye Height lower location measurement

8 Appendix C – Transmitter Preset calibration

8.1.1 Preset Calibration

8.1.1.1 Reference

USB4 Specification Table 3-5

8.1.1.2 Objective

Find and Burn the optimized preset for the platform.

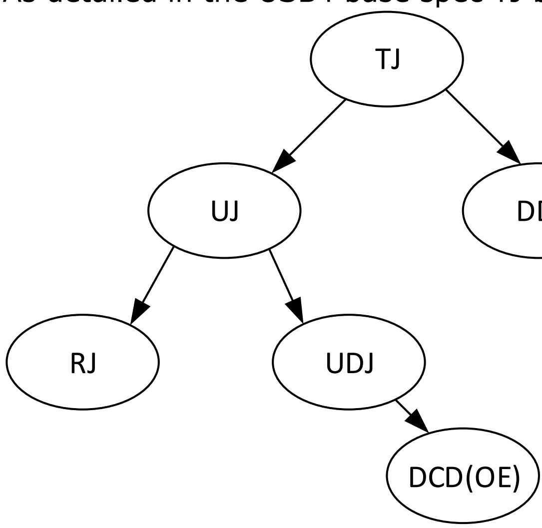
8.1.1.3 Method

1. Connect the DUT according to Figure 2.
2. Choose a USB4 speed to start with.
3. Configure DUT transmitter to output PRBS15, preset 0 on all lanes with SSC turned on.
4. The cables from the plug test fixture to the scope shall be de-embedded.
5. Measurement should be done with a calibrated reference equalizer (CTLE and DFE) as described in Appendix B.
6. Measurement shall be done with a reference CDR modeled by a 2^{nd} order PLL response which drives High-Pass-Filter (HPF) rejection mask with 3dB bandwidth at 5MHz and damping factor of 0.94; no average and no interpolation to be used. Scope BW shall be as specified in 6.1
7. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 40Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 40Mpts. The evaluated record length shall be 500us per channel.
    - Pattern length -> Periodic
    - Jitter separation method shall be suitable for cross talk on signal
    - Adjust vertical scale to fit signal into scope screen.
    - Referenced to 1E-13 statistics.
8. Capture DDJ results for lane 0.
9. Repeat the test for all remaining USB4 transmit presets until Preset 15 of the Transmitter Equalization Preset Table above.
10. Repeat the test for all remaining USB4 lanes.
11. For each lane, choose and Burn the preset that provides minimum DDJ.
12. Repeat the procedure above for all supported USB4 speeds.

9 Appendix D – Jitter Term Definition

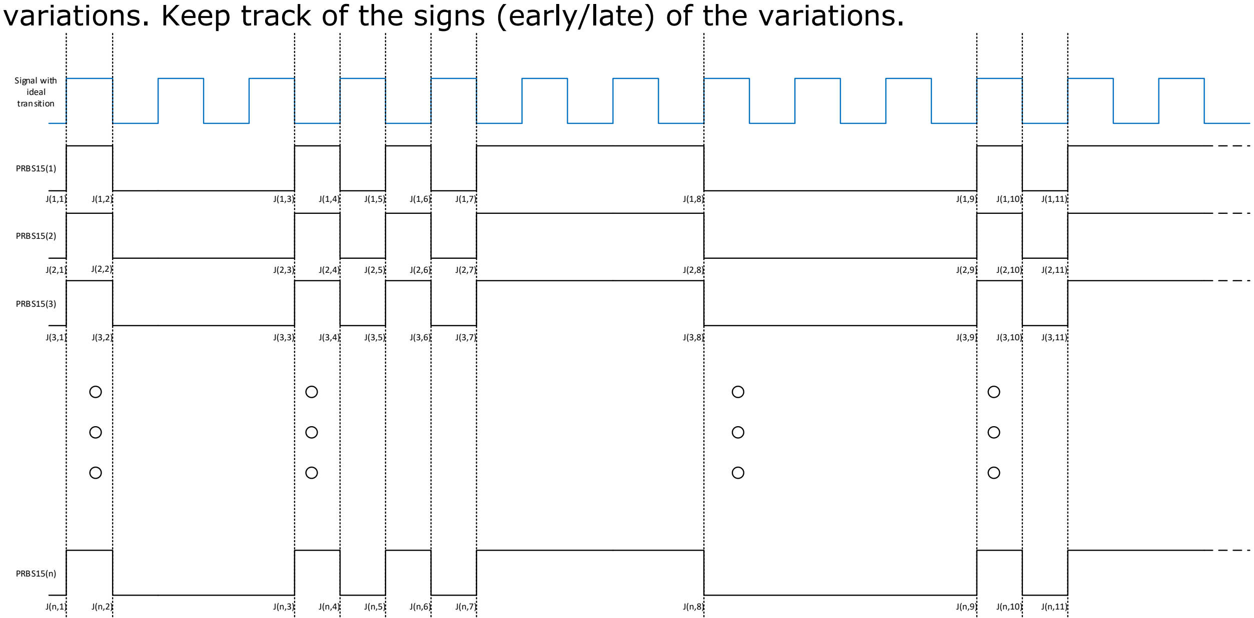
9.1 High level of Total jitter decomposition

As detailed in the USB4 base spec TJ break down will looks as the following diagram:



9.2 DDJ

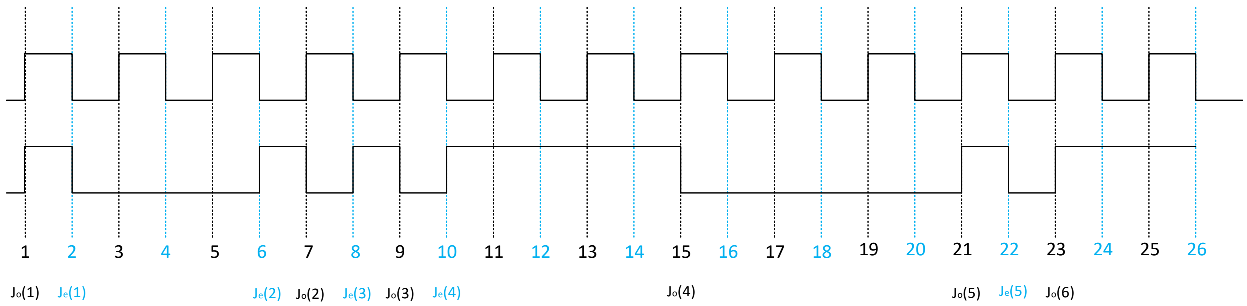
A repeating PRBS15 pseudo-random test pattern is used.
Synchronize the pattern repetition and average the crossing times sufficiently per each specific zero-crossing to remove the effects of uncorrelated jitter. The mean time of each crossing is then compared to the expected time of the crossing, and a set of 16,384 timing variations is determined. DDJ is the range (max-min) of the timing variations. Keep track of the signs (early/late) of the variations.



$$\mathrm{DDJ} = \underset{i}{\mathrm{Max}}\left\{\underset{m}{\mathrm{average}}[J(m,i)]\right\} - \underset{i}{\mathrm{Min}}\left\{\underset{m}{\mathrm{average}}[J(m,i)]\right\}$$

9.3 DCD

DCD mean even-odd jitter. The deviation of the time of each transition from an ideal clock at the signaling rate is measured. Even-odd jitter is defined as the magnitude of the difference between the average deviation of all even-numbered transitions and the average deviation of all odd-numbered transitions, where determining if a transition is even or odd is based on possible transitions but only actual transitions are measured and averaged.



$$DCD = abs[average(Jo) - average(Je)]$$

10 Appendix E – Interoperability with Thunderbolt™ 3 (TBT3) Systems

When TBT3 Mode is established, an Adapter shall run at a TBT3-Compatible speed. A Router Assembly shall support TBT3-Compatible Gen2 Speed (10.3125Gbps). A Router Assembly may also optionally support TBT3-Compatible Gen3 Speed (20.625Gbps).

10.1 Gen2 and Gen3 Captive Device Transmitter Compliance

A Router Assembly Transmitter shall meet the specifications described in this CTS, except for the following set of parameters that shall be used instead of the values specified above. Listed just the gap from the above in section 3 and 4.

10.1.1 Gen2 and Gen3 SSC Down Spread Rate Measurement

10.1.1.1 Reference

SSC_Down_Spread_Rate - USB4 Specification Table 13-1

10.1.1.2 Requirement

35KHz ≤ SSC_Down_Spread_Rate ≤ 37KHz

Test Objective and Test Method stay the same.

10.1.2 Gen2 and Gen3 SSC Phase Deviation Measurement

10.1.2.1 Reference

SSC_Phase_Deviation - USB4 Specification Table 13-1

10.1.2.2 Requirement

2.5ns p-p ≤ SSC_Phase_Deviation ≤ 18.5ns p-p

Test Objective and Test Method stay the same.

10.1.3 Gen2 Minimum Unit Interval Measurement

10.1.3.1 Reference

UI USB4 Specification Table 13-1.

10.1.3.2 Requirement

96.9406ps ≤ Minimum Unit Interval ≤ 96.9988ps

Test Objective and Test Method stay the same.

10.1.4 Gen3 Minimum Unit Interval Measurement

10.1.4.1 Reference

UI USB4 Specification Table 13-1.

10.1.4.2 Requirement

48.4703ps ≤ Minimum Unit Interval ≤ 48.4994ps

Test Objective and Test Method stay the same.

10.1.5 Gen2 Average Unit Interval Measurement

10.1.5.1 Reference

UI USB4 Specification section 13-1.

10.1.5.2 Requirement

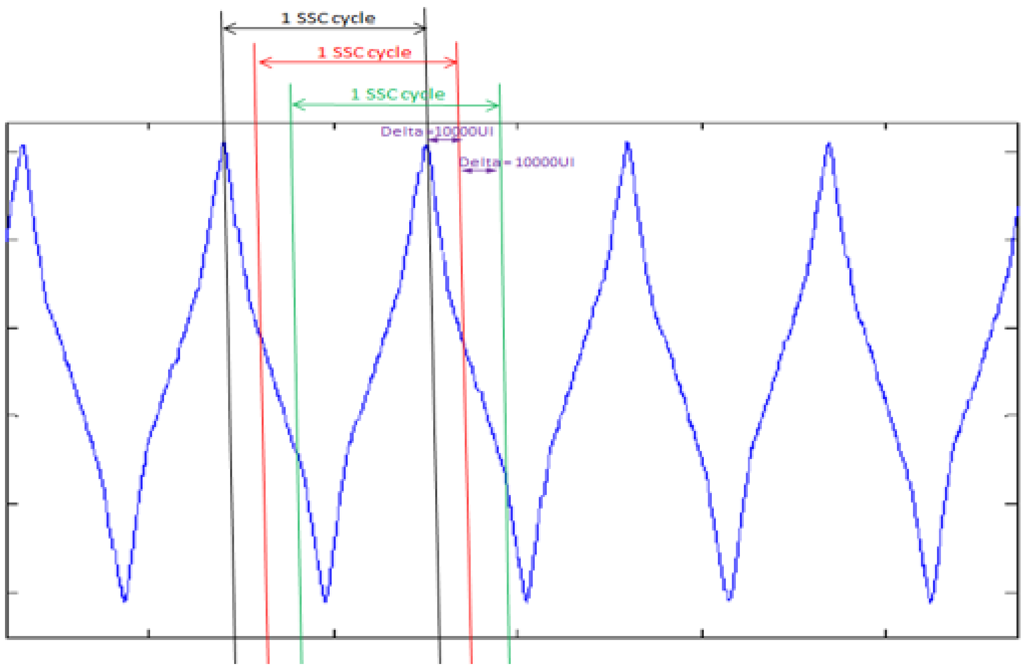
97.1348ps ≤ Average Unit Interval ≤ 97.2420ps

10.1.5.3 Test Objective

Confirm that the Average Unit Interval under all conditions does not exceed minimum or maximum limits of the USB4 Specification.

10.1.5.4 Test Method

1. Choose a supported USB4 Gen2 10.3125GHZ speed.
2. Configure DUT transmitter to output PRBS31 on all lanes with SSC turned on.
3. The cables from the plug test fixture to the scope shall be de-embedded.
4. Capture the waveform and process it with the oscilloscope:
    - Sampling Rate ≥ 80GSa/s
    - Evaluate 27Mpts per channel when using 80GSa/s. For higher sample rate use memory depth in the same ratio to 27Mpts. The evaluated record length shall be 337.5us per channel.
    - No CDR, no average and no interpolation to be used.
    - Adjust vertical scale to fit signal into scope screen.
    - Scope BW shall be as specified in 6.1.
5. Use mathematical analysis to measure the Average Unit Interval over a window at the size of one SSC cycle, determined by the SSC_Down_Spread_Rate.



6. Measure Average Unit Interval over different windows that uniformly cover the scope capture over more than 10 SSC cycles with 10000 UI window jump.
7. If Max Average Unit Interval > 97.2420ps **or** Min Average Unit Interval < 97.1348ps then **Fail**
8. Repeat the test for all remaining USB4 lanes

10.1.6 Gen2 and Gen3 TX Frequency Variation Training Measurement

Frequency variation testing during Link training for TBT3 frequencies is not needed.

10.2 Gen2 and Gen3 Captive Device Receiver Compliance

Two different from the section 4 above:

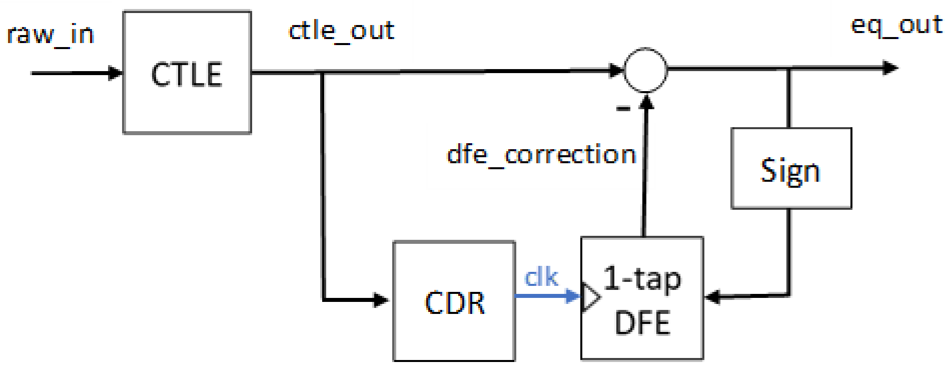
1. SSC profile that shall be added from the pattern generator is as following:

- SSC with modulation wave shape triangle
- Modulation frequency for both Gen2 and Gen3 is 36KHz:
- Spread deviation from +400ppm up to -5400ppm

2. Signal Frequency Variations Training test for TBT3 frequencies is not needed

11 Appendix F – Applying DFE method

USB4 eye measurements at TP3 shall be performed using reference RX equalization function comprised of CTLE and DFE, as described in figure bellow. The eye shall be characterized after convolving the raw input signal with the CTLE function and subtracting the DFE correction implemented as constant voltage timed by the CDR clock aligned to the CTLE output. The DFE correction extends as a constant voltage from the mid-point between the UI clock and the previous clock to the mid-point between the UI clock and the next clock. In this way, the DFE correction is applied half a UI before the data sampling and changes again half a UI after the data sampling.



Waveforms example: