USB Type-C Cable-Connector Assemblies Compliance Test Solutions

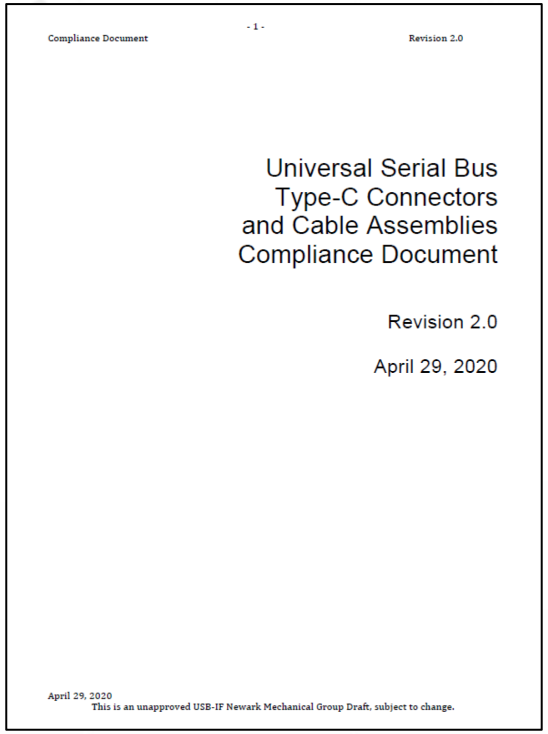
Keysight Technologies	2021.01.20

Test Solution Overview using Keysight's Network Analyzer
with Enhanced TDR Application

KEYSIGHT
TECHNOLOGIES

Revision History

Revision	Date	Changes
Initial 1.0	30-Dec-2020	• Initial release • Ref 1: Universal Serial Bus Type-C Connectors and Cable Assemblies Compliance Document Revision 2.0 (Apr 29, 2020) • Ref 2: Universal Serial Bus Type-C Cable and Connector Specification Release 2.0 (August 2019)



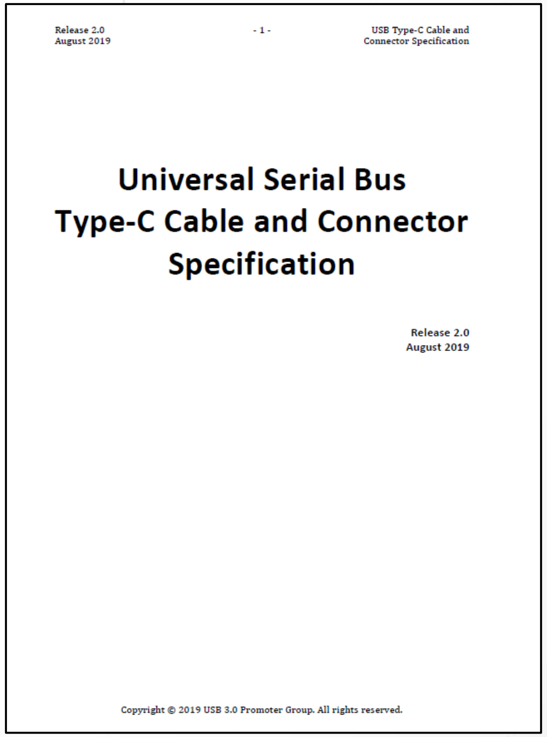
Compliance Document - 1 - Revision 2.0

Universal Serial Bus
Type-C Connectors
and Cable Assemblies
Compliance Document

Revision 2.0

April 29, 2020

April 29, 2020
This is an unapproved USB-IF Newark Mechanical Group Draft, subject to change.



Release 2.0
August 2019 - 1 - USB Type-C Cable and
Connector Specification

Universal Serial Bus
Type-C Cable and Connector
Specification

Release 2.0
August 2019

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KEYSIGHT TECHNOLOGIES

Purpose

This slide shows how to conduct USB4.0/Type-C Cable & Connector Assemblies Compliance Test using Keysight S9x011A/B Enhanced TDR application on

- E5080B-4K0: 4-port test set, 9 kHz to 20 GHz or
- P5024A/25A-400 Keysight Streamline USB series VNA or
- M9804A-400 PXI Multiport VNA

Keysight Digital Standard Program

Our solutions are driven and supported by Keysight experts who involved actively in international standards committees to deliver faster and highest quality compliance tests.

SUPERSPEED USB

PCI EXPRESS

JEDEC

HDMI
HIGH-DEFINITION MULTIMEDIA INTERFACE

SERIAL ATA

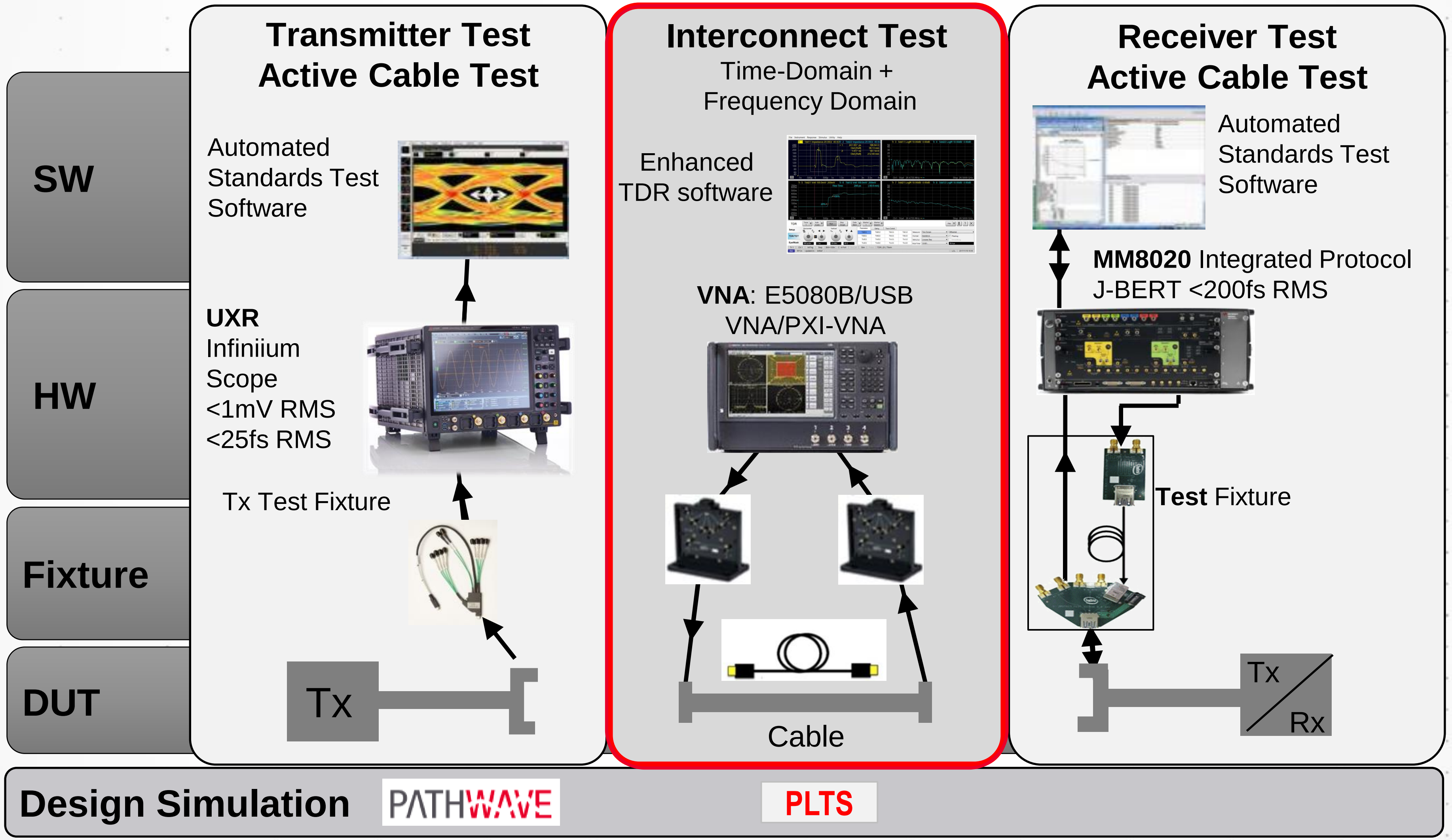
mipi
mobile industry processor interface

OIF OPTICAL INTERNETWORKING FORUM

KEYSIGHT TECHNOLOGIES

Keysight HSD Total Solutions

Example: USB Type-C



Keysight Solutions to Enable the Type-C Revolution

GET THE RESOLUTION YOU NEED

Fast to Market

MOIs and setup files are ready to enable a quick and easy test setup

Standard Compliance

Complete solution to test the interoperability and compliance of standards requirements.

One Solution for All

Accelerate your design, debug, characterization to compliance in one complete solution

USB Type-C Cable/Connector Compliance Test

Functional Signal Plan

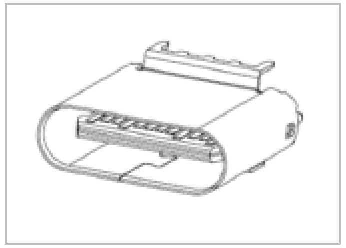


Figure 2-1 USB Type-C Receptacle Interface (Front View)

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GND	TX1+	TX1−	VBUS	CC1	D+	D−	SBU1	VBUS	RX2−	RX2+	GND
GND	RX1+	RX1−	VBUS	SBU2	D−	D+	CC2	VBUS	TX2−	TX2+	GND
B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1

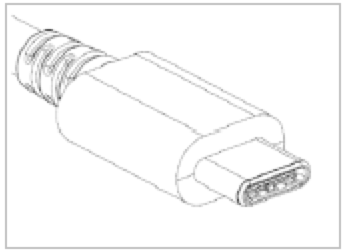


Figure 2-2 USB Full-Featured Type-C Plug Interface (Front View)

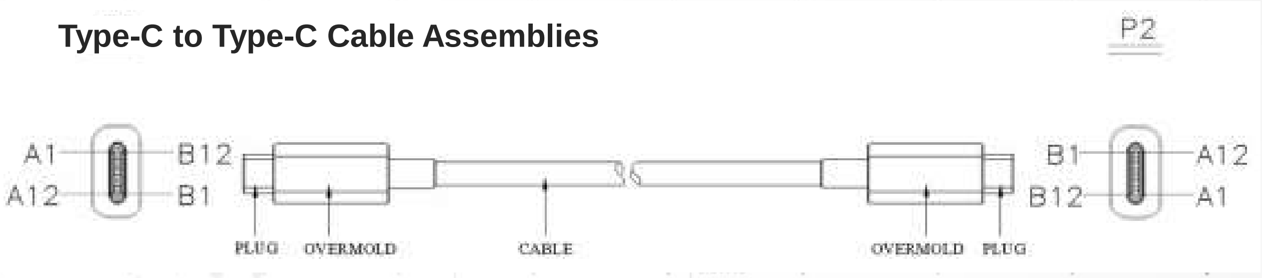
A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1
GND	RX2+	RX2−	VBUS	SBU1	D−	D+	CC	VBUS	TX1−	TX1+	GND
GND	TX2+	TX2−	VBUS	VCONN			SBU2	VBUS	RX1−	RX1+	GND
B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12

Ref: USB Type-C Spec R2.0 - August 2019; Fig2.1 and Fig2.2

USB Type-C Cable/Connector Compliance Test Cable Assembly

Type-C to Type-C Cable Assemblies

- USB2.0 Pairs
- USB3.2 Gen 1 and USB4 Gen2 Pairs
- USB3.2 Gen 2 and USB4 Gen 2 Pairs
- USB4 Gen3 Pairs

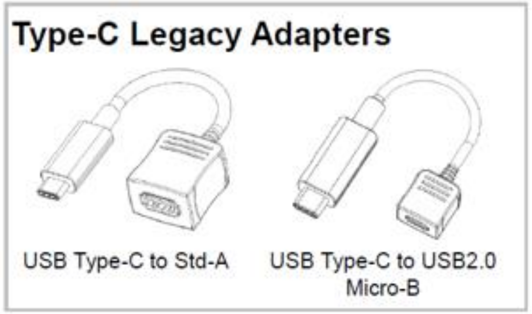


Type-C to Legacy USB Cable Assembles

- USB2.0: Std-A to Type-C, Type-C to Std-B, Type-C to Mini-B, Type-C to Micro-B
- USB3.1 Gen 2: Std-A to FF Type-C, FF Type-C to Std-B, FF Type-C to Micro-B

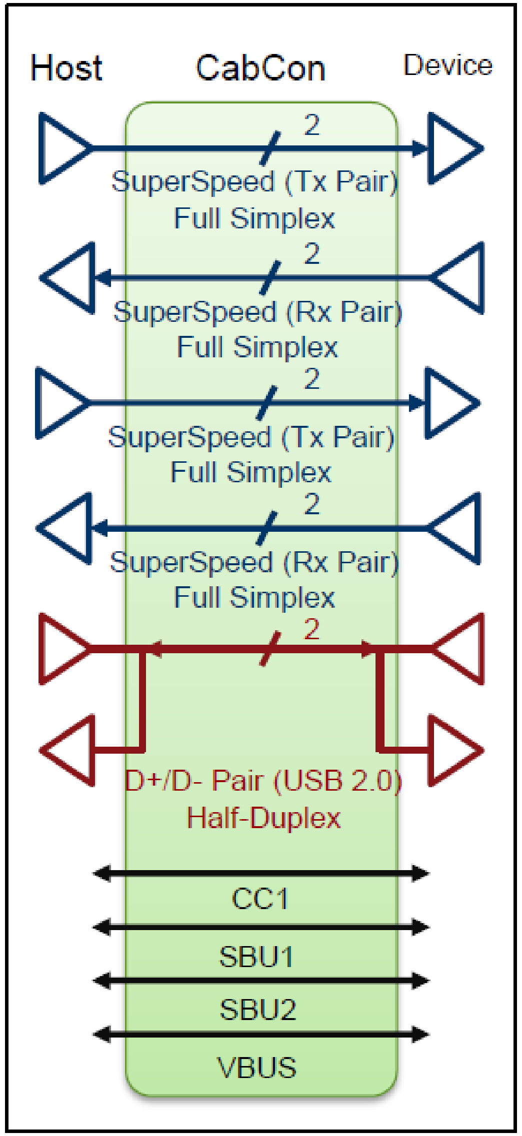
Type-C to Legacy USB Adapters

- USB2.0 Type-C to USB2.0 Micro-B
- USB FF Type-C to USB3.1 Std-A



Ref: USB Type-C Spec R2.0 - August 2019; Table 3.1/3.2/3.3

USB Type-C Cable/Connector Compliance Test Cable Assembly

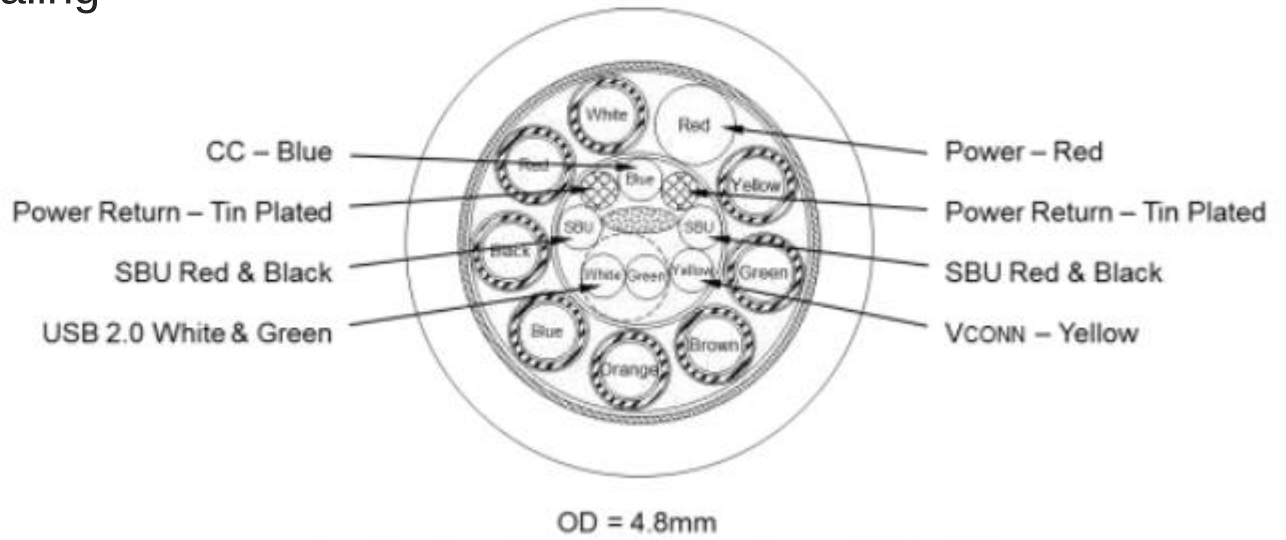


SuperSpeed (TX/RX) Signals Pairs

- Coaxial wires, twin-axial or shielded twisted pairs.
- Used for either USB3.2 or USB4 signaling.
- Shielding is needed for signal integrity and EMC performance.

D+/D- Signal Pairs

- Typical unshielded twisted pair (UTP).
- Intended to transmit the USB2.0 Low-Speed, Full-Speed and High-Speed signaling



Coax are TX/RX pairs – specific pairs not defined in cable

USB Type-C Cable/Connector Compliance

Test Measurement Parameters (Type-C to Type-C Passive Cable Assemblies)

Time Domain Measurements	Frequency Domain Measurements
• D+/D- Impedance • D+/D- Propagation Delay • D+/D- Intra-pair Skew • [Raw Cable] Characteristic Impedance • [Raw Cable] Intra-Pair Skew • [Mated Connector] Differential Impedance • [Low Speed Signal] Characteristic Impedance	• D+/D- Pair Attenuation • Channel Metrics (ILfitatNq, IMR, IXT, IRL) • Channel Operating Margin, COM (Normative – USB4 Gen3) • Differential to Common Mode Conversion • Cable Shielding Effectiveness • [Raw Cable] Differential Insertion Loss • [Mated Connector] Channel Metrics (ILfitatNq, IMR, IXT, IRL) • [Mated Connector] Diff. Insertion Loss (ILfitatNq) • [Mated Connector] Diff. Return Loss • [Mated Connector] Diff. NEXT & FEXT between SS Signal Pairs • [Mated Connector] Diff. NEXT & FEXT between D+/D- Pair and SS Signal Pairs • [Mated Connector] Differential to Common Mode Conversion • Diff Insertion Loss • Diff Return Loss • Diff. NEXT & FEXT between SS Signal Pairs • Diff. NEXT & FEXT between D+/D- Pair and SS Signal Pairs • [Low Speed Signal] Crosstalk, VBUS Loop L/C, Coupling Factor • [Low Speed Signal] Coupling between CC and Differential D+/D- • [Low Speed Signal] Single-ended Coupling between CC and D+/D- • [Low Speed Signal] Coupling between VBUS and Differential D+/D- • [Low Speed Signal] Single-ended Coupling between SBU_A and SBU_B • [Low Speed Signal] Single-ended Coupling between SBU_A/SBU_B and CC • [Low Speed Signal] Coupling between SBU_A/SBU_B and Differential D+/D-

Note: Normative parameters for the USB Type-C cable assembly are highlighted in blue

USB Type-C Cable/Connector Compliance

Test Measurement Parameters (Type-C to Legacy USB Cable Assemblies)

Time Domain Measurements	Frequency Domain Measurements
• D+/D- Impedance • D+/D- Propagation Delay • D+/D- Intra-pair Skew • Differential impedance of SS Pairs • [Raw Cable] Characteristic Impedance • [Raw Cable] Intra-Pair Skew • [Mated Connector] Differential Impedance	• D+/D- Pair Attenuation • Channel Metrics (ILfitatNq, IMR, IXT, IRL) • Differential to Common Mode Conversion • Cable Shielding Effectiveness • [Raw Cable] Differential Insertion Loss • [Mated Connector] Diff. Insertion Loss (ILfitatNq) • [Mated Connector] Diff. Return Loss • [Mated Connector] Diff. NEXT & FEXT between SS Signal Pairs • [Mated Connector] Diff. NEXT & FEXT between D+/D- Pair and SS Signal Pairs • [Mated Connector] Differential to Common Mode Conversion • Diff Insertion Loss • Diff. NEXT & FEXT between SS Signal Pairs • Diff. NEXT & FEXT between D+/D- Pair and SS Signal Pairs

Note: Normative parameters for the USB Type-C cable assembly are highlighted in blue

USB Type-C Cable/Connector Compliance

Test Measurement Parameters (Type-C to Legacy USB Adapter Assemblies)

Time Domain Measurements	Frequency Domain Measurements
• D+/D- Impedance (USB 2.0) • D+/D- Intra-pair Skew (USB 2.0) • [Raw Cable] Characteristic Impedance • [Raw Cable] Intra-Pair Skew • [Mated Connector] Differential Impedance	• D+/D- Pair Attenuation • Channel Metrics (ILfitatNq, IMR, IXT, IRL) • Differential to Common Mode Conversion • Cable Shielding Effectiveness • [Raw Cable] Differential Insertion Loss • [Mated Connector] Diff. Insertion Loss (ILfitatNq) • [Mated Connector] Diff. Return Loss • [Mated Connector] Diff. NEXT & FEXT between SS Signal Pairs • [Mated Connector] Diff. NEXT & FEXT between D+/D- Pair and SS Signal Pairs • [Mated Connector] Differential to Common Mode Conversion • Diff. Insertion Loss • Diff. Return Loss • Diff. NEXT/FEXT between SS Signal Pairs • Diff. NEXT/FEXT between D+/D- and SS Signal Pairs

Note: Normative parameters for the USB Type-C cable assembly are highlighted in blue

USB Type-C Cable/Connector Compliance

Frequency Domain Measurements

- Channel Operating Margin (COM)
- D+/D- Pair Attenuation
- ILfitatNq, IMR, IXT, IRL, Differential to Common Mode Conversion
- Cable Shielding Effectiveness
- Insertion Loss (Informative)
- Return Loss (Informative)
- NEXT/FEXT between SS Signal Pairs (Informative)
- NEXT/FEXT between D+/D- and SS Signal Pairs (Informative)
- [Raw Cable] Insertion Loss (Informative)
- [Mated Connector] Channel Metrics (ILfitatNq, IMR, IXT, IRL)
- [Mated Connector] Insertion Loss (Informative)
- [Mated Connector] Return Loss (Informative)
- [Mated Connector] NEXT/FEXT between SS Signal Pairs (Informative)
- [Mated Connector] NEXT/FEXT between D+/D-and SS Signal Pairs (Informative)
- [Mated Connector] Differential to Common Mode Conversion (Informative)
- [Low Speed Signal] Crosstalk, VBUS Loop L/C, Coupling Factor

Time Domain Measurements

- D+/D- Impedance
- D+/D- Propagation Delay
- D+/D- Intra-pair Skew
- Differential Impedance
- [Raw Cable] Characteristic Impedance (Informative)
- [Raw Cable] Intra-Pair Skew (Informative)
- [Mated Connector] Diff. Impedance (Informative)
- [Low Speed Signal] Characteristic Impedance

Conventional

Vector Network Analyzer

Conventional

TDR Scope

One-box Solution

New Solution

Enhanced TDR App

ENA Option TDR Compliance Test Solution

ENA Option TDR is used worldwide by certified test centers of USB, HDMI, DisplayPort, MHL, Thunderbolt and SATA

USB Type-C Cable/Connector Compliance Test Configuration

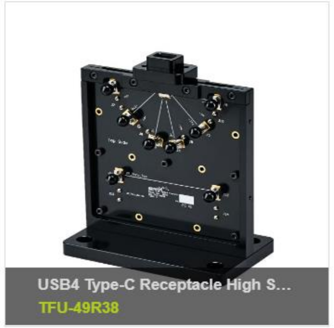
1. ENA Mainframe (*1)

- E5080B-4K0: 4-port test set, 9 kHz to 20 GHz
- S96011B Enhanced Time Domain Analysis
- ECal Module (N4433A; 4-ports)

Other option: P5024A/P5025A USB VNA and M9804A/M9805A PXI Multiport VNA

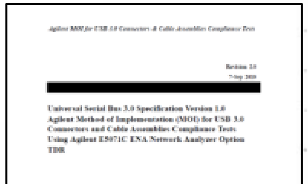
2. USB Type-C Test Fixtures

Fixtures for testing USB4/Type-C connectors and cable assemblies are available for purchase through Luxshare-ICT. http://en.luxshare-ict.com/product/index.html



3. Keysight MOIs and State Files Configurations

www.keysight.com/find/ena-tdr_compliance
www.keysight.com/find/ena-tdr_usbtype-c-cabcon



Universal Serial Bus 3.0 Specification Version 1.0
Agilent Method of Implementation (MOI) for USB 3.0 Connectors and Cable Assemblies Compliance Tests Using Agilent E5071C ENA Network Analyzer Option TDR

Step-by-step procedure on how to measure the specified parameters in the specification document using ENA Option TDR.

USB Type-C Cable/Connector Compliance Test

STATE FILE AVAILABLE FOR EASY SETUP

3 State files:

1 — **Type-C to Type-C Passive Cable Assemblies**
- [High Speed] Measurement Parameters
- [Low Speed Signal] Measurement Parameters

2 — **Type-C to Legacy USB Cable Assemblies**

3 — **Type-C to Legacy USB Adapter Assemblies**

3 Simple Steps

Recall State File (*.tdr)

↓

Setup & Calibration

↓

Run to verify Pass/Fail

Note: State file includes both Normative and Informative measurements parameters

USB Type-C Cable/Connector Compliance Test

STATE FILE AVAILABLE FOR EASY SETUP

[Type-C to Type-C Passive Cable Assemblies, High-Speed]

Channel 1- Time Domain	Channel 2- Frequency Domain
5.1. D+/D- Diff. Impedance (Tr 1 & Tr 5) 5.2. D+/D- Intra-pair Skew (Tr 3) 5.3. D+/D Propagation Delay (Tr 4) 5.9.[Raw Cable] Impedance (Tr 2 & Tr 6) 5.10.[Raw Cable] Intra Pair Skew (Tr 3) 5.12.[Mated Connector] Diff. Impedance (Tr 15 & Tr 16)	5.4. D+/D Pair Attenuation (Tr 11) 5.5 Channel Metrics (eH, eW, ILfitatNq, IMR and IXT) 5.6 Channel Operating Margin, COM (Normative – USB4 Gen3) 5.7. Differential to Common Mode Conversion (Tr 10) 5.8.Cable Shielding Effectiveness (Tr 13 & Tr 14) 5.11.[Raw Cable] Differential Insertion Loss (Tr 9) 5.13.[Mated Connector] Diff. Insertion Loss (ILfitatNq) (Tr 12) 5.14. [Mated Connector] Diff. Return Loss. (Tr 17) 5.15. [Mated Connector] Diff. NEXT & FEXT between SS Signal Pairs (Tr 18) 5.16. [Mated Connector] Diff. NEXT & FEXT between D+/D Pair and SS Signal Pairs (Tr 19) 5.17. [Mated Connector] Differential to Common Mode Conversion (Tr 20) 5.18. Diff Insertion Loss (Tr 21) 5.19. Diff Return Loss (Tr 22) 5.20. Diff. NEXT & FEXT between SS Signal Pairs (Tr 23) 5.21. Diff. NEXT & FEXT between D+/D Pair and SS Signal Pairs (Tr 24)

[Type-C to Type-C Passive Cable Assemblies, Low-Speed]

Channel 1- Time Domain	Channel 2- Frequency Domain
5.22. [Low Speed Signal] Characteristic Impedance (Tr 25 & Tr 26 / Tr 27 & Tr 28)	5.23. [Low Speed Signal] Crosstalk, VBUS Loop L/C, Coupling Factor (Tr 29) 5.24. [Low Speed Signal] Coupling between CC and Differential D+/D- (Tr 30) 5.25. [Low Speed Signal] Single-ended Coupling between CC and D+/D- (Tr 31 & Tr 32) 5.26. [Low Speed Signal] Coupling between VBUS and Differential D+/D- (Tr 33) 5.27. [Low Speed Signal] Single-ended Coupling between SBU_A and SBU_B (Tr 34) 5.28. [Low Speed Signal] Single-ended Coupling between SBU_A/SBU_B and CC (Tr 35) 5.29. [Low Speed Signal] Coupling between SBU_A/SBU_B and Differential D+/D- (Tr 36)

USB Type-C Cable/Connector Compliance Test

STATE FILE AVAILABLE FOR EASY SETUP

[Type-C to Legacy USB Cable Assemblies]

Channel 1- Time Domain	Channel 2- Frequency Domain
5.1. D+/D- Diff. Impedance (Tr 1 & Tr 5) 5.2. D+/D- Intra-pair Skew (Tr 3) 5.3. D+/D Propagation Delay (Tr 4) 5.8 [Raw Cable] Diff. Impedance (Tr 2 & Tr 6) 5.9 [Raw Cable] Intra-Pair Skew (Tr 3) 5.11 [Mated Connector] Diff. Impedance (Tr 15 & Tr 16) 5.17. Diff. Impedance (Tr 25 & Tr 26)	5.4. D+/D Pair Attenuation (Tr 11) 5.5 Channel Metrics (eH, eW, ILfitatNq, IMR and IXT) 5.6. Differential to Common Mode Conversion (Tr 10) 5.7.Cable Shielding Effectiveness (Tr 13 & Tr 14) 5.10 [Raw Cable] Differential Insertion Loss (Tr 9) 5.12 [Mated Connector] Diff. Insertion Loss (ILfitatNq) (Tr 12) 5.13. [Mated Connector] Diff. Return Loss. (Tr 17) 5.14. [Mated Connector] Diff. NEXT & FEXT between SS Signal Pairs (Tr 18) 5.15. [Mated Connector] Diff. NEXT & FEXT between D+/D- Pair and SS Signal Pairs (Tr 19) 5.16. [Mated Connector] Differential to Common Mode Conversion (Tr 20) 5.18. Diff Insertion Loss (Tr 21) 5.19. Diff. NEXT between SS Signal Pairs (Tr 23) 5.20. Diff. NEXT & FEXT between D+/D- Pair and SS Signal Pairs (Tr 24)

[Type-C to Legacy USB Adapter Assemblies]

Channel 1- Time Domain	Channel 2- Frequency Domain
5.1. D+/D- Diff. Impedance (Tr 1 & Tr 5) 5.2. D+/D- Intra-pair Skew (Tr 3) 5.7[Raw Cable] Diff. Impedance (Tr 2 & Tr 6) 5.8 [Raw Cable] Intra-Pair Skew (Tr 3) 5.10 [Mated Connector] Diff. Impedance (Tr 15 & Tr 16)	5.3. D+/D Pair Attenuation/Diff. Insertion Loss (Tr 11) 5.4 Channel Metrics (eH, eW, ILfitatNq, IMR and IXT) 5.5 Differential to Common Mode Conversion (Tr 10) 5.6 Cable Shielding Effectiveness (Tr 13 & Tr 14) 5.9 [Raw Cable] Differential Insertion Loss (Tr 9) 5.11 [Mated Connector] Diff. Insertion Loss (Tr 12) 5.12 [Mated Connector] Diff. Return Loss. (Tr 17) 5.13 [Mated Connector] Diff. NEXT & FEXT between SS Signal Pairs (Tr 18) 5.14 [Mated Connector] Diff. NEXT & FEXT between D+/D- Pair and SS Signal Pairs (Tr 19) 5.15 [Mated Connector] Differential to Common Mode Conversion (Tr 20) 5.16 Diff. Insertion Loss (Tr 21) 5.17 Diff. Return Loss (Tr 22) 5.18 Diff. NEXT between SS Signal Pairs (Tr 23) 5.19 Diff. NEXT & FEXT between D+/D- Pair and SS Signal Pairs (Tr 24)

Normative and **Informative** Parameters

USB Type-C Cable/Connector Compliance Test

Setup & Calibration Procedure

Setup

- Manual or automatic setup by recalling a state file.
- State files for Enhanced TDR will be provided for fast setup and minimized human error.

Calibration

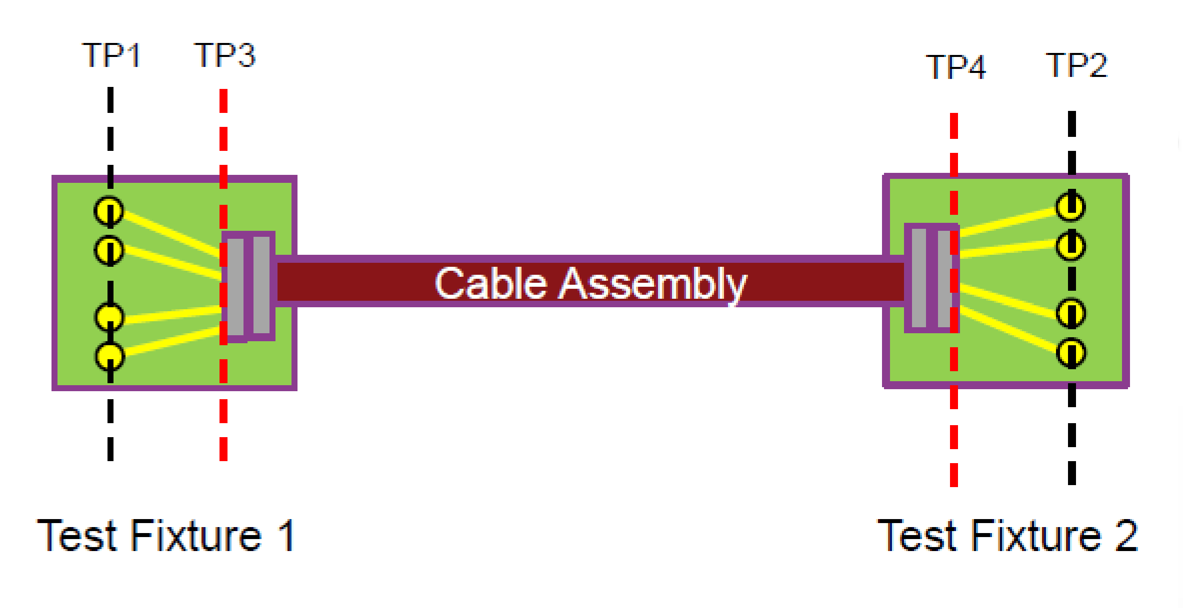
- Calibration for frequency-domain measurements shall be performed to remove the unwanted test fixture trace effect.
- ECal+ De-embedding are available with Enhanced TDR.

Measurement

- The Enhanced TDR can be used to perform all measurements.
- Compliance standard tools by USB-IF are required for pass/fail judgment of Channel Operating Margin (COM), ILfitatNq, IMR, IXT, IRL, differential to common mode conversion.

USB Type-C Cable/Connector Compliance Test Calibration

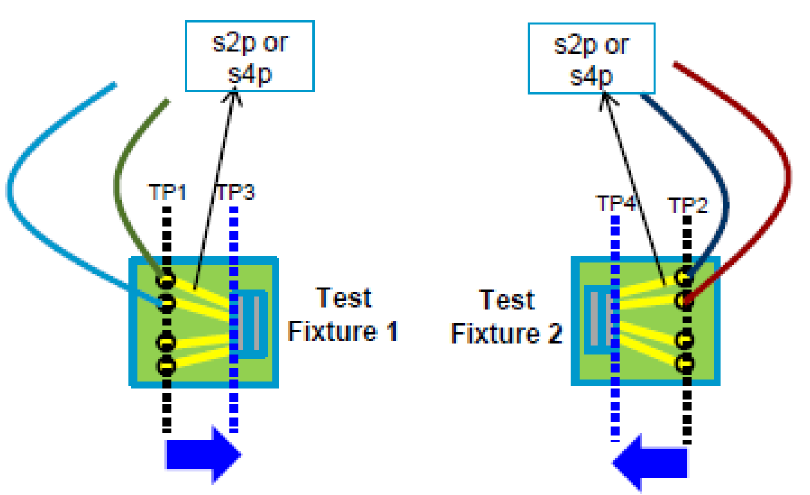
- Calibration shall be performed to remove the unwanted test fixture trace effect.
- The procedures of 2xThru de-embedding are the official procedure introduced in the USB Type-C Compliance Specification.



USB Type-C Cable/Connector Compliance Test

Calibration

Step 1: ECal+ De-embedding

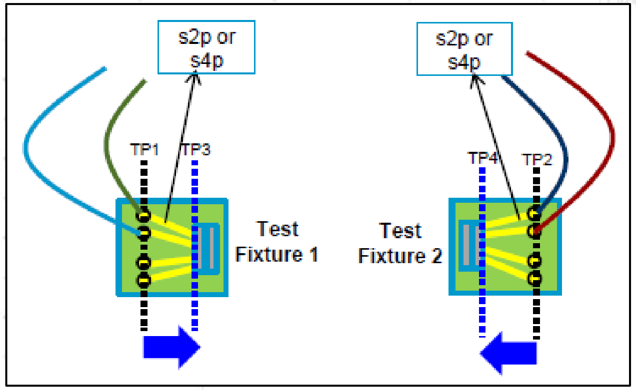
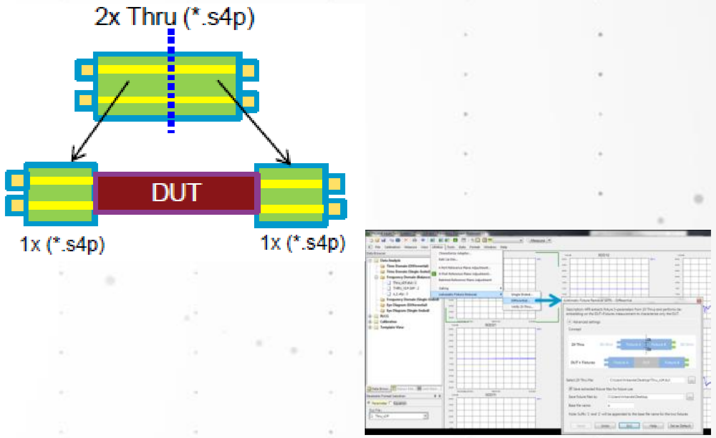
Full calibration with ECal	De-embedding S-parameters of fixture traces
	
• Full 4-port calibration is performed using the 4-port ECal module (i.e. N4433A). • The reference plane is established at the end of RF cables connected to the ENA's test ports.	• S-parameter Touchstone files (*.s2p or .s4p) of fixture traces are excluded from total performance in frequency-domain by using the de-embedding function of the ENA. • The reference plane is moved to the edge of USB connectors on the test fixtures (TP1->TP3 & TP2->TP4). • The electrical length of 2x Thru is equal to the length of the trace between TP1 and TP3 plus the length of the trace between TP2 and TP4.

Note from USB.org: Other calibration methods are allowed. For example, the automatic fixture removal or AFR; the 2X THRU structure may be used for AFR.

USB Type-C Cable/Connector Compliance Test

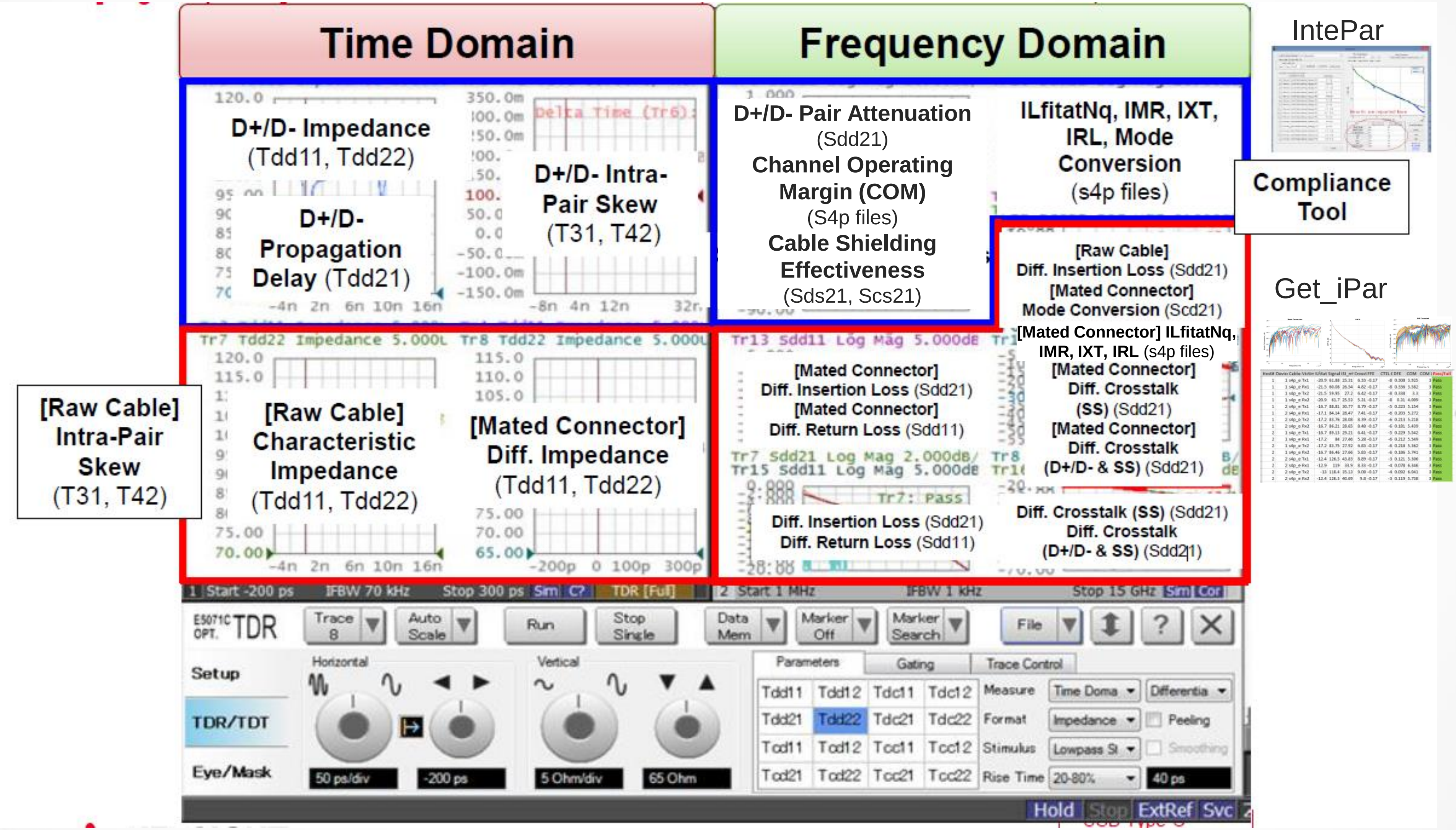
Calibration

Alternative: Creating De-embedding files using AFR (S96007) or PLTS software (N1930B)

1. Full calibration with ECal	2. Measure 2xThru standards	3.Create de-embedding files by AFR
		
• Perform full 4-port calibration using the ECal module (i.e. N4433A).	• Perform 4-port measurement and save 4-port S-parameter file (*.s4p).	• Launch AFR/PLTS software on PC • Import measured 4-port file (*.s4p) • Create two de-embedding files (*.s4p) • Change port configuration (optional)

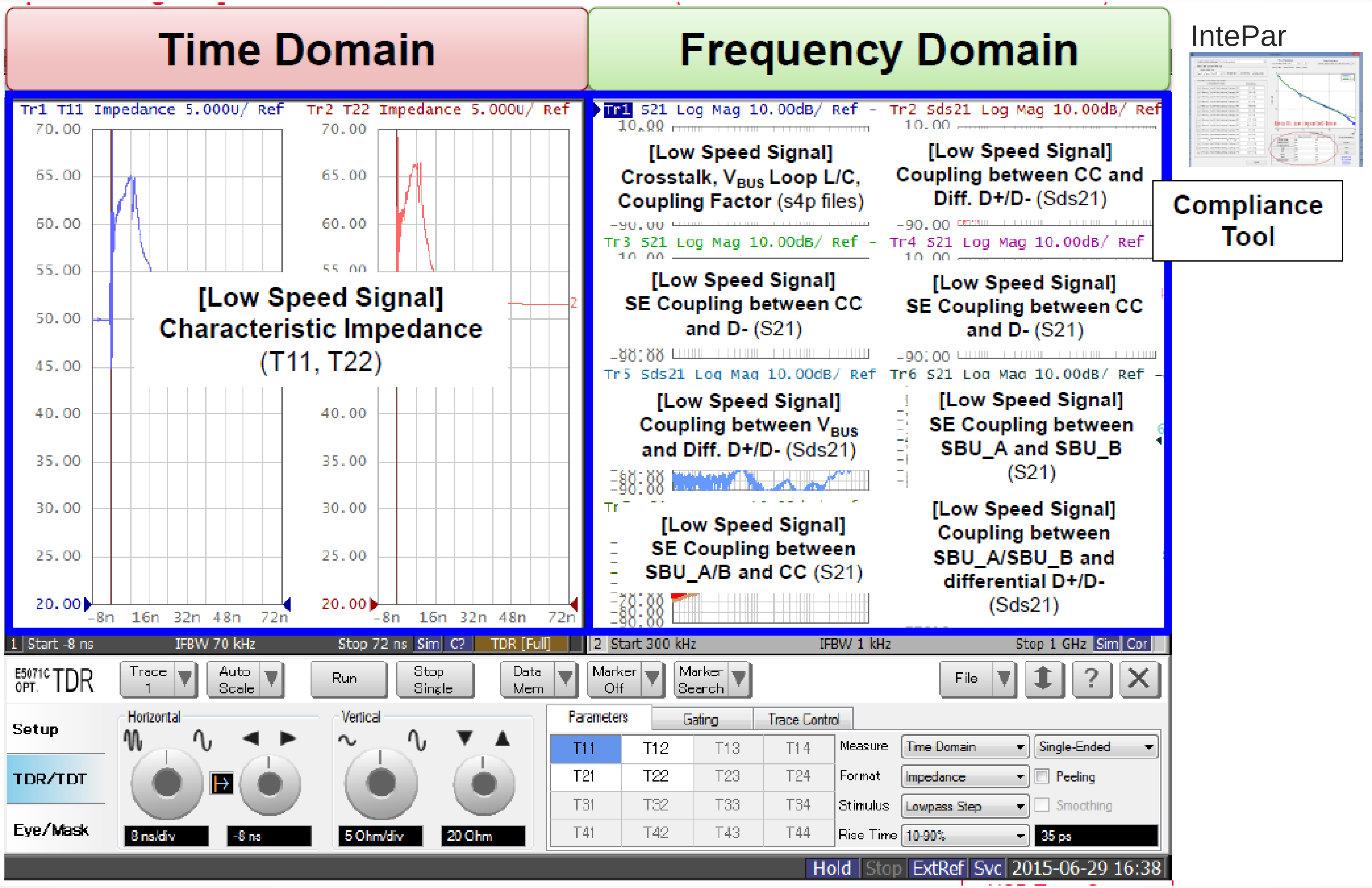
USB Type-C Cable/Connector Compliance Test

[High Speed] Measurement Parameters (Normative & Informative)



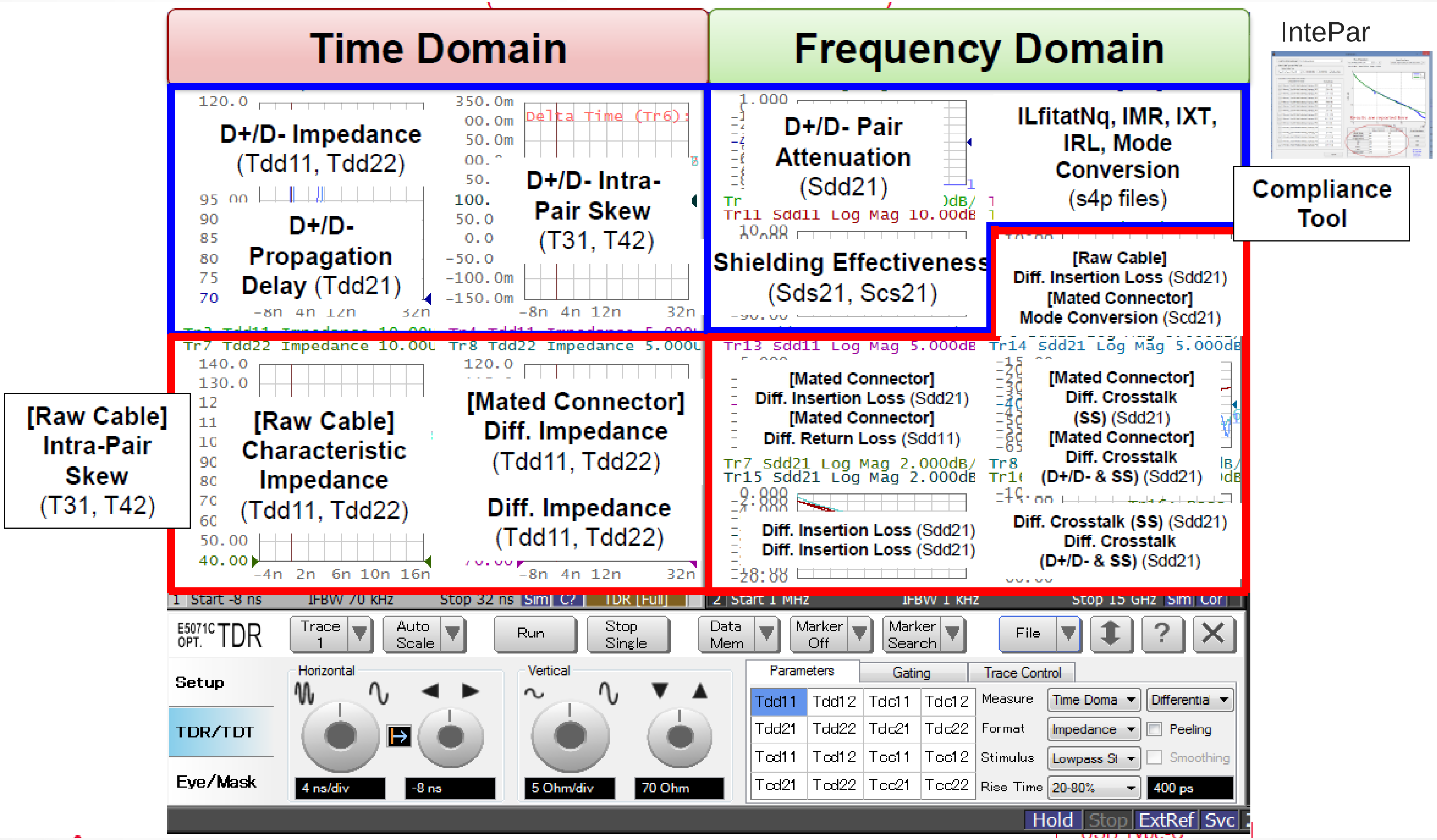
USB Type-C Cable/Connector Compliance Test

[Low Speed] Measurement Parameters (Normative& Informative)



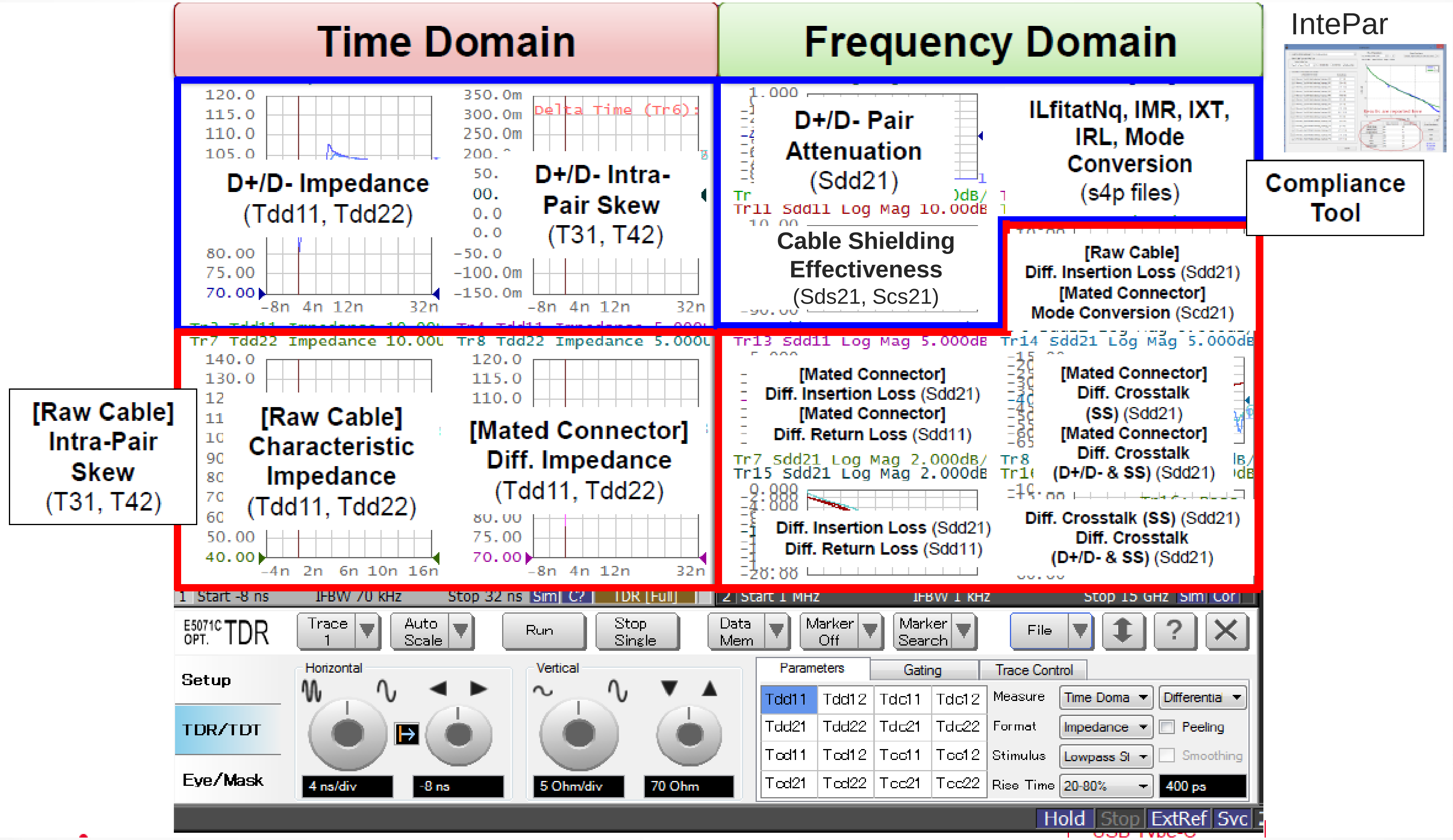
USB Type-C Cable/Connector Compliance Test

Measurement Parameters (Normative& Informative)



USB Type-C Cable/Connector Compliance Test

Measurement Parameters (Normative& Informative)

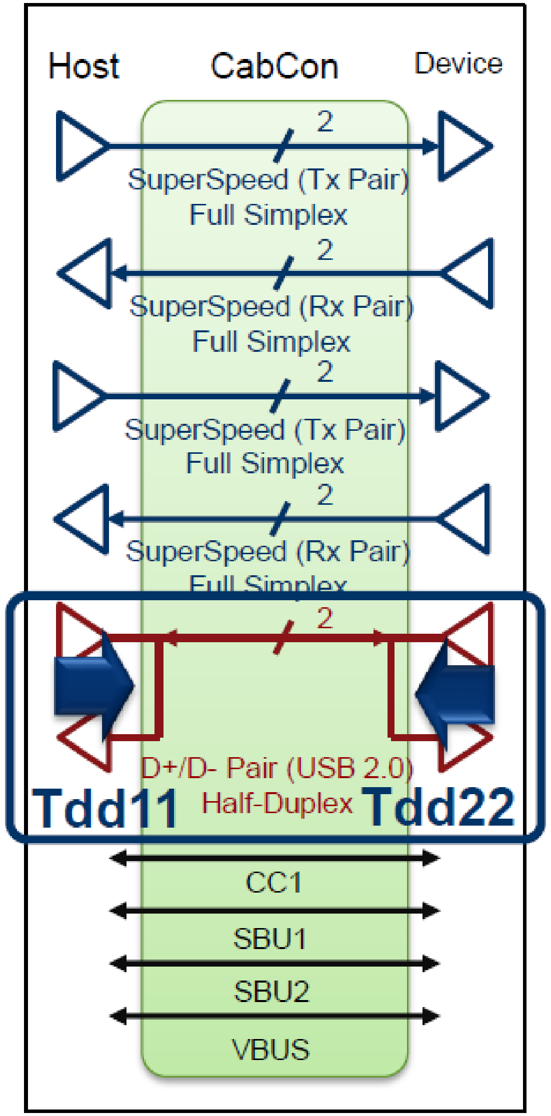


Normative Vs Informative Measurement

Normative	• Normative information is provided to allow interoperability of components designed to USB specification. • Mandatory requirement to meet USB compliance specification. • Pass/Failure criteria to meet compliance.
Informative	• Informative information, when provided, may illustrate possible design implementations or design targets. • Aim to help cables/connectors manufacturers to manage the procurement. • Not part of the USB Type-C compliance requirements.

Normative

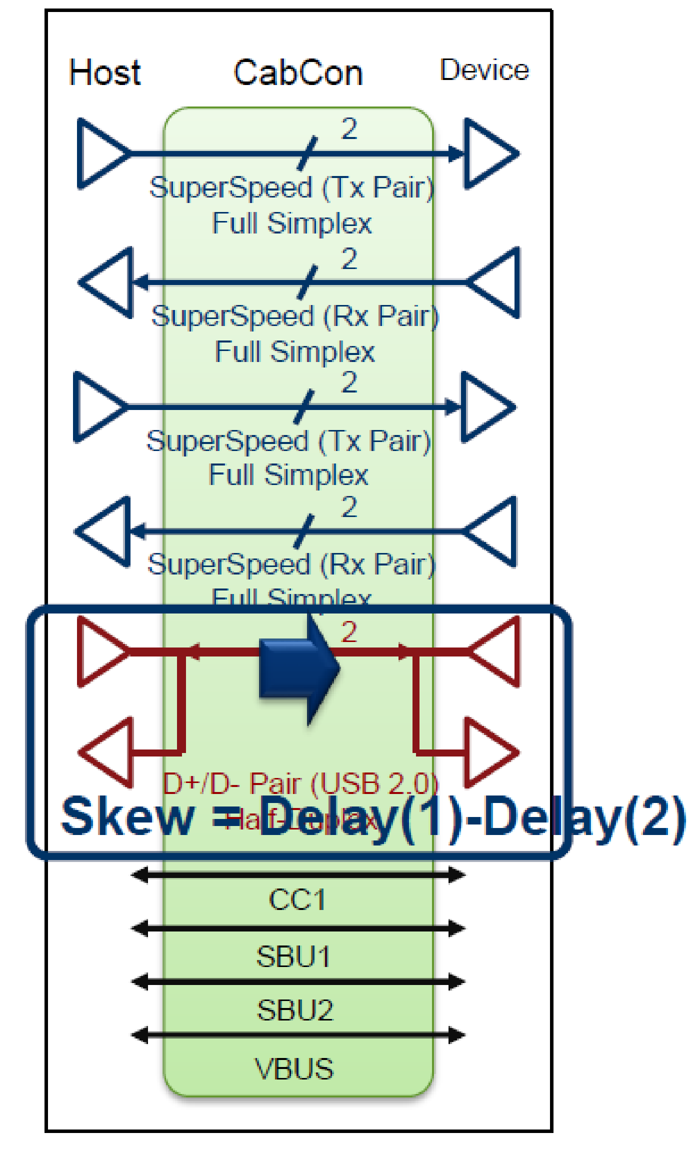
D+/D- Differential Impedance



- EIA 364-108
- Multiple reflections from impedance mismatches cause noise at the receiver. Therefore, the impedance profile provides an indication of multiple reflection induced noise.
- This test ensures that the D+/D− lines of the entire cable assembly have the proper impedance.

DUT Type	Limit
Type-C to Type-C passive cable assembly	75 Ω Min 105 Ω Max
Type-C to legacy cable assembly	
Type-C to legacy adapter assembly	
Note: The impedance should be evaluated using a 400ps (20%-80%) rise time	

D+/D- Intra-Pair Skew

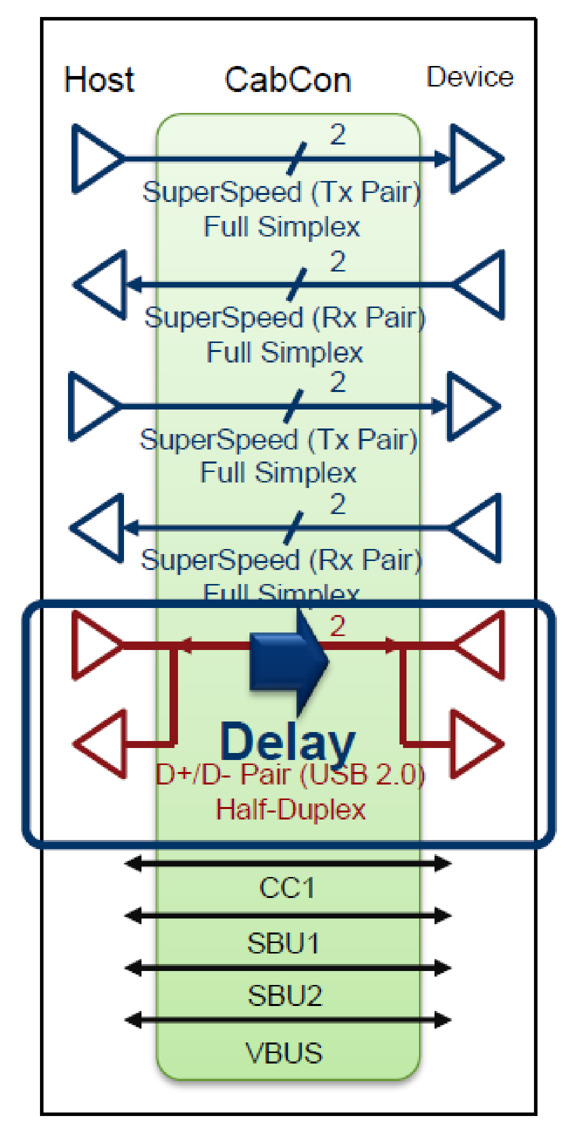


- EIA 364 – 103
- This test ensures that the signal on both the D+ and D− lines of cable assembly arrive at the receiver at the same time.

DUT Type	Limit
Type-C to Type-C passive cable assembly	100 ps max.
Type-C to legacy cable assembly	
Type-C to legacy adapter assembly	20 ps max.
Note: The measurement should be evaluated using a 400ps (20%-80%) rise time	

Normative

D+/D- Propagation Delay



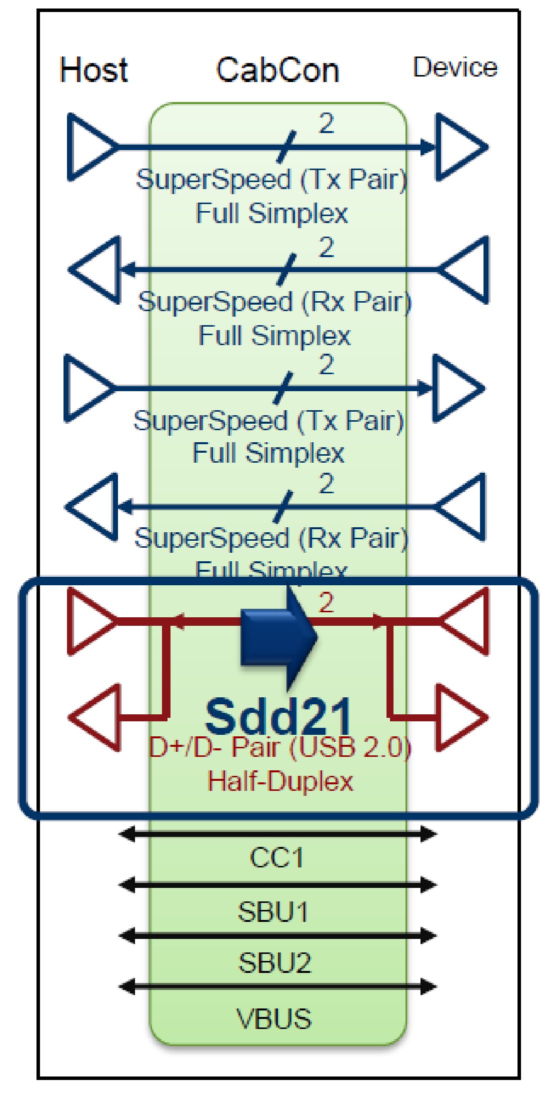
- EIA 364-103
- The purpose of the test is to verify the end-to-end propagation of the D+/D− lines of the cable assembly.

DUT Type	Limit
Type-C to Type-C passive cable assembly	26ns max.
Type-C to legacy cable assembly	10ns max for USB Type-C to Micro-B cable assembly; 20ns max for all other USB Type-C to legacy USB cable assemblies.
Note: The impedance should be evaluated using a 400ps (20%-80%) rise time	

KEYSIGHT TECHNOLOGIES

Normative

D+/D- Pair Attenuation

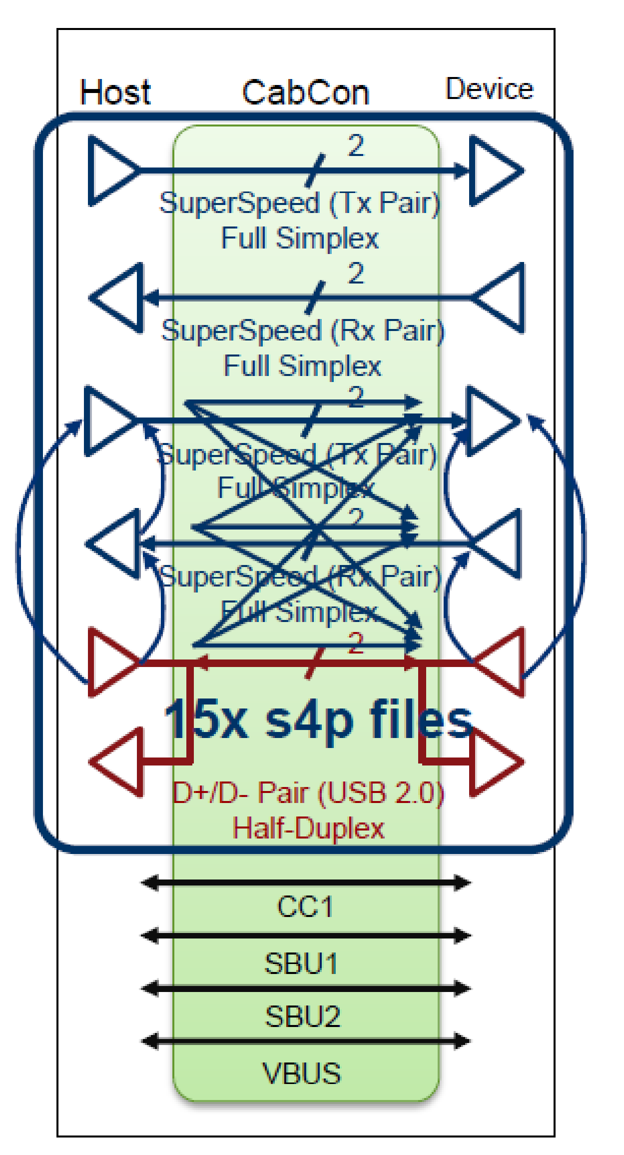


- EIA 364 – 101
- This test ensures the D+/D− pair of a cable assembly are able to provide adequate signal strength to the receiver in order to maintain a low error rate.

DUT Type	Limit
Type-C to Type-C passive cable assembly	≥ −1.02 dB @ 50 MHz ≥ −1.43 dB @ 100 MHz ≥ −2.40 dB @ 200 MHz ≥ −4.35 dB @ 400 MHz
Type-C to legacy cable assembly	
Type-C to legacy adapter assembly	−0.7 dB max @ 400 MHz
Note: The impedance should be evaluated using a 400ps (20%-80%) rise time	

Normative

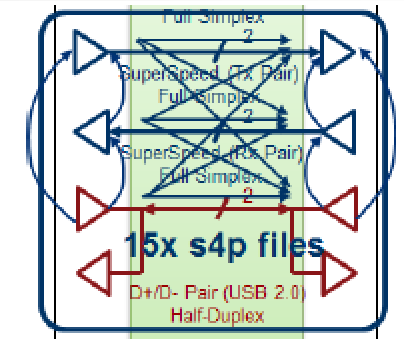
Channel Metrics



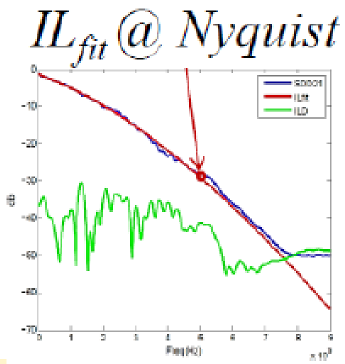
- Five parameters (ILfitatNq, IMR, IXT, IRL and Differential to Common-Mode Conversion) are calculated for SS+ pairs and D+/D- pair.
- USB Type-C standard tool provided by USB-IF will do the pass/fail judgment for five parameters based on measured Touchstone files.

DUT Type	Signal Integrity Compliance Requirements
Type-C to Type-C Cable Assembly (USB 3.2 Gen1/Gen2 and USB4 Gen2) Type-C to Legacy Cable Type-C to Legacy Adapter	ILfitatNq, IMR, IRL, INEXT and IFEXT, IDDXT_1NEXT+FEXT and, IDDXT_2NEXT, Differential-to -Common-Mode Conversion. (15x s4p or 3x s8p or 1x s12p file) USB-IF compliance tool: IntePar.exe https://compliance.usb.org/files/IntePar_1p6.zip
Type-C to Type-C Cable Assembly (USB4 Gen3 only)	COM + ILfitatNq, IMR, IRL, INEXT and IFEXT, IDDXT_1NEXT+FEXT and, IDDXT_2NEXT, Differential-to -Common-Mode Conversion. (44x s4p or 10x s8p or 5x s12p or 2x s20p) USB-IF compliance tool: Get_iPar.exe https://compliance.usb.org/files/Ger_iPar_v0p91a_release.zip

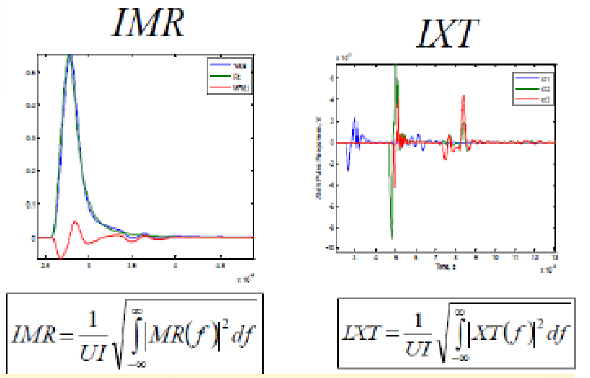
Channel Metrics using Compliance Tool



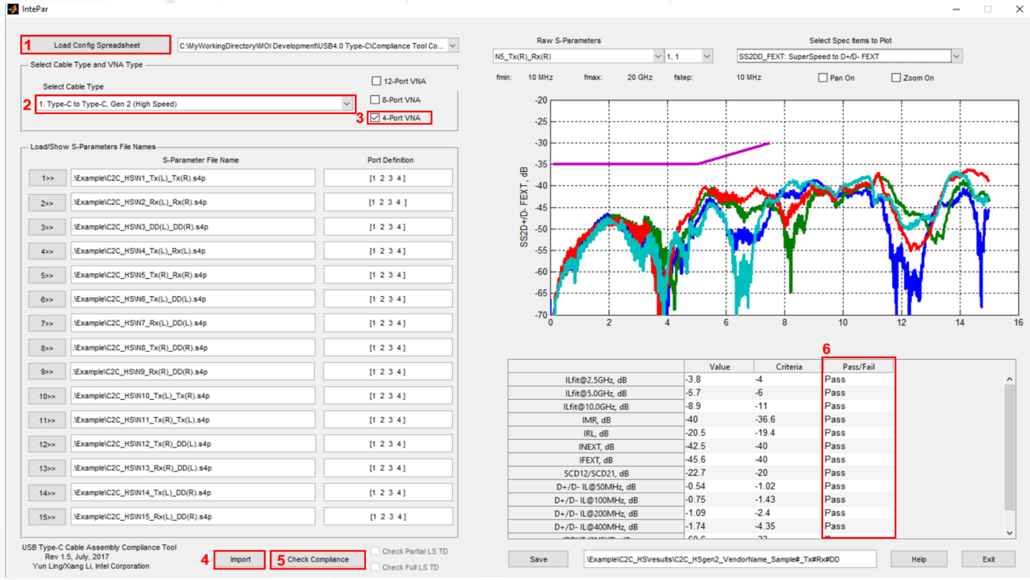
Touchstone S-parameter files (*s4p) are saved and imported to the tool



Differential insertion loss is fitted with a smooth function to obtain the insertion loss at Nyquist frequency of 2.5/5/10 GHz (ILfitatNq).



Integrated crosstalk (IXT), integrated multi-reflection (IMR) etc response are calculated from S-parameter files.

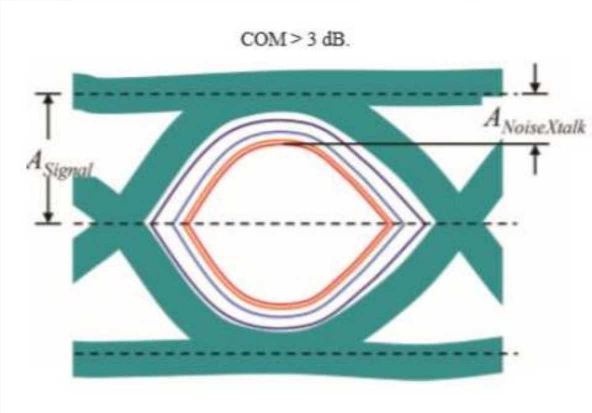


The USB-IF compliance tool performs pass/fail judgment based on the previous calculation.

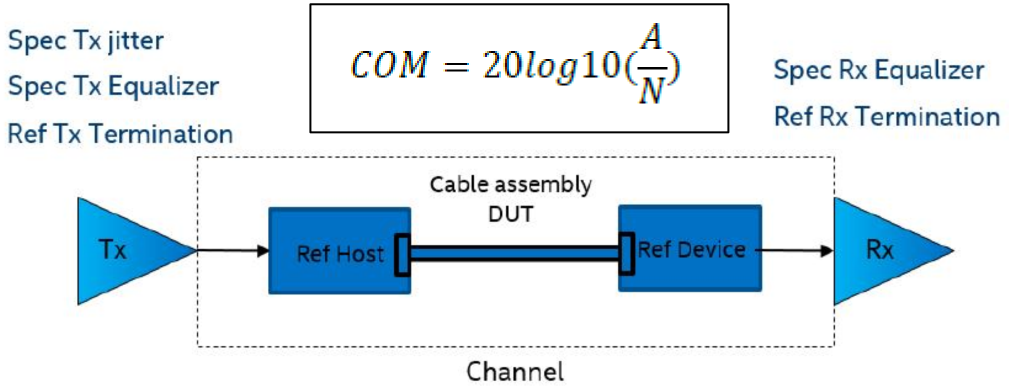
Channel Operating Margin (COM) for USB4 Gen3 (New)

- COM is the channel signal-to-noise ratio to measure the channel electrical quality.
- The technical detail of COM may be found in IEEE Std 802.3bj™-2014 Clause 93a.

Threshold Limit: ≥ 3dB



$$COM = 20log10(\frac{A}{N})$$



where A is the signal amplitude and N is the combined noise at BER (bit -error-ratio), which includes the noise sources from ISI, crosstalk, transmitter jitter, etc.

- Collaterals needed to calculate COM:
  - Measured cable S-parameters
  - Reference hosts/devices
  - Reference Tx/Rx termination
  - COM configuration file

Normative

Channel Operating Margin (COM) for USB4 Gen3 (New)

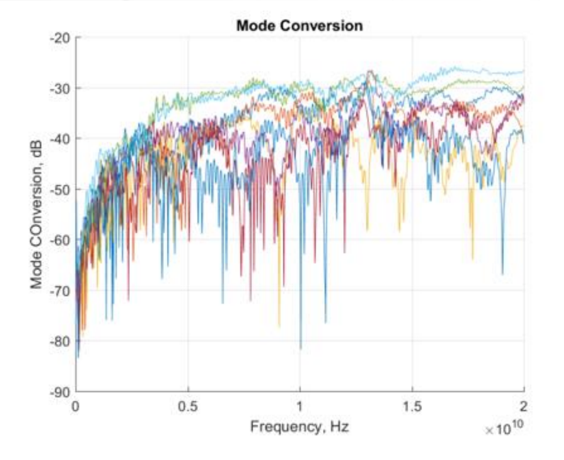
- Channel Operating Margin (COM) is verified using a standard compliance tool (Get_iPar.exe) provided by USB IF after the measurements have made.
- Full S-parameters touchstone files for High-speed TX/RX pairs + D+/D- Pairs to run the COM tool.

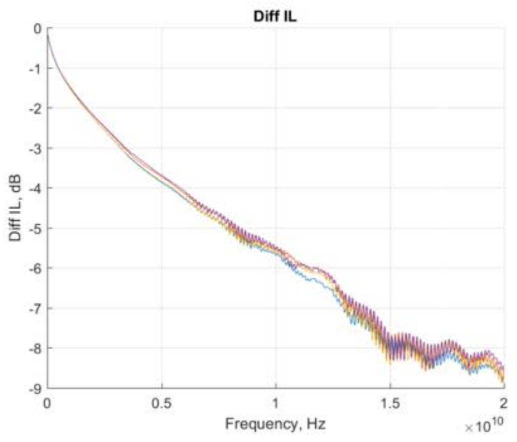
4-Ports VNA
44x s4p required:
- 28x TX/RX Pairs
- 16x D+/D- and TX/RX XT

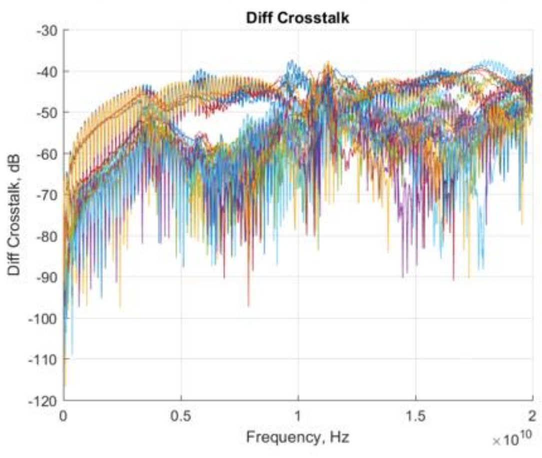
8-Ports VNA
10x s8p required:
- 6x TX/RX Pairs
- 4x D+/D- and TX/RX XT

20-Ports VNA
2x s20p required:
- 1x TX/RX Pairs
- 1x D+/D- and TX/RX XT

Improve throughput of total measurement with M9804/05A PXIe VNA Multiport Configuration!



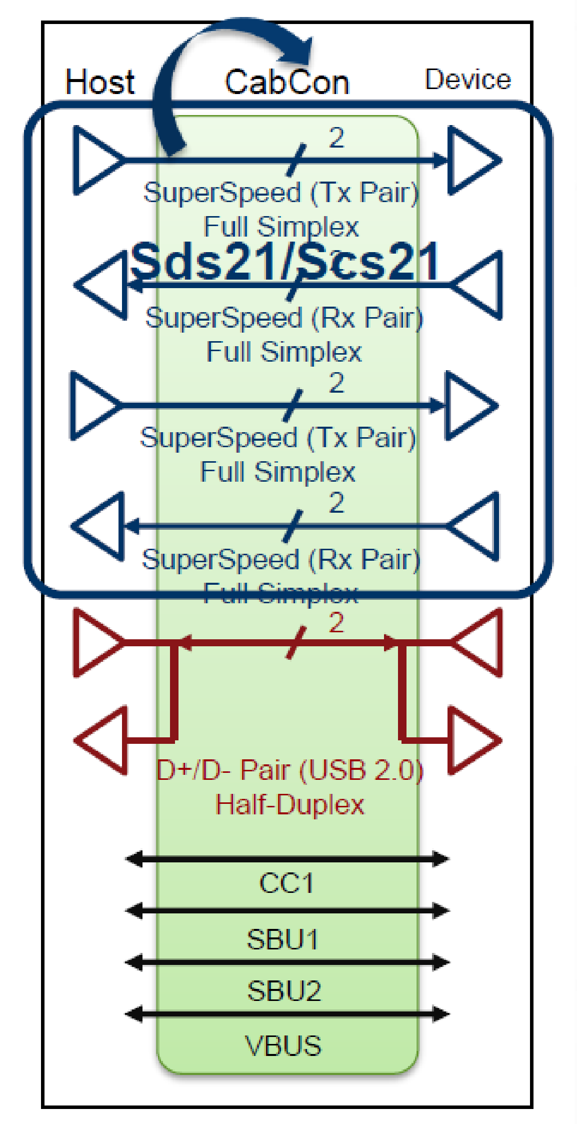




Host#	Devic	Cable	Victim	ILfitat	Signal	ISI_m	Crosst	FFE	CTEL G	DFE	COM	COM L	Pass/Fail
1	1	s4p_e	Tx1	-20.9	61.88	25.31	6.33	-0.17	-8	0.308	3.925	3	Pass
1	1	s4p_e	Rx1	-21.5	60.08	26.54	4.82	-0.17	-8	0.336	3.582	3	Pass
1	1	s4p_e	Tx2	-21.5	59.95	27.2	6.42	-0.17	-8	0.338	3.3	3	Pass
1	1	s4p_e	Rx2	-20.9	61.7	25.53	5.31	-0.17	-8	0.31	4.009	3	Pass
1	2	s4p_e	Tx1	-16.7	88.81	30.77	8.79	-0.17	-5	0.223	5.154	3	Pass
1	2	s4p_e	Rx1	-17.1	84.14	28.47	7.41	-0.17	-6	0.203	5.272	3	Pass
1	2	s4p_e	Tx2	-17.2	83.76	28.08	8.39	-0.17	-6	0.213	5.218	3	Pass
1	2	s4p_e	Rx2	-16.7	86.21	28.65	8.48	-0.17	-6	0.181	5.439	3	Pass
2	1	s4p_e	Tx1	-16.7	89.13	29.21	6.41	-0.17	-5	0.229	5.542	3	Pass
2	1	s4p_e	Rx1	-17.2	84	27.46	5.28	-0.17	-6	0.212	5.549	3	Pass
2	1	s4p_e	Tx2	-17.2	83.75	27.92	6.83	-0.17	-6	0.218	5.362	3	Pass
2	1	s4p_e	Rx2	-16.7	86.46	27.66	5.83	-0.17	-6	0.186	5.741	3	Pass
2	2	s4p_e	Tx1	-12.4	126.5	43.83	8.89	-0.17	-3	0.121	5.306	3	Pass
2	2	s4p_e	Rx1	-12.9	119	33.9	8.33	-0.17	-4	0.078	6.346	3	Pass
2	2	s4p_e	Tx2	-13	118.4	35.13	9.08	-0.17	-4	0.092	6.041	3	Pass
2	2	s4p_e	Rx2	-12.4	126.3	40.69	9.8	-0.17	-3	0.119	5.738	3	Pass

Normative

Cable Shielding Effectiveness

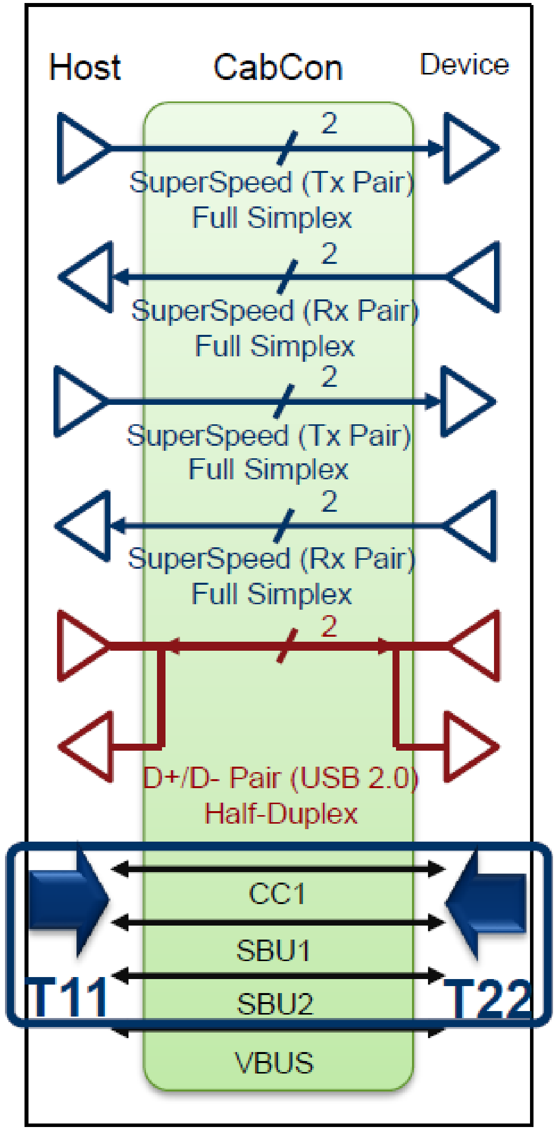


- Measures the radio frequency interference (RFI) level from the cable assembly
- The coupling factor from differential Tx / Rx pairs to single-ended cable shield (i.e. Sds21/Scs21) is calculated.
- USB Type-C standard tool provided by USB-IF will do the pass/fail judgment based on Touchstone files.

DUT Type	Limit
Type-C to Type-C (USB 3.2) Cable Assembly	Differential model: ≤ -55 dB for f ≤1.6 GHz, ≤ -50 dB for 1.6 GHz ≤ f ≤ 4.0 GHz and 5 GHz ≤ f ≤ 6 GHz Common model: ≤ -40 dB for f ≤ 1.6 GHz, ≤ -35 dB for 1.6 GHz ≤ f ≤ 4 GHz and 5 GHz ≤ f ≤ 6 GHz
Type-C to USB Legacy (USB 3.2) Cable Assembly	Differential model: ≤ -49 dB for f ≤1.6 GHz, ≤ -44 dB for 1.6 GHz ≤ f ≤4GHz and 5 GHz ≤ f ≤ 6 GHz Common model: ≤ -34 dB for f ≤1.6 GHz, ≤ -29 dB for 1.6 GHz ≤ f ≤ 4 GHz and 5 GHz ≤ f ≤ 6 GHz
Type-C to Standard-A Receptacle Adapter	Differential model: ≤ -44 dB for f ≤1.6 GHz, ≤ -39 dB for 1.6 GHz ≤ f ≤4 GHz and for 5 GHz ≤ f ≤ 6 GHz Common model: ≤ -24dB for f ≤1.6 GHz, ≤ -24 dB for 1.6 GHz ≤ f ≤ 4 GHz and for 5 GHz ≤ f ≤ 6 GHz

Normative

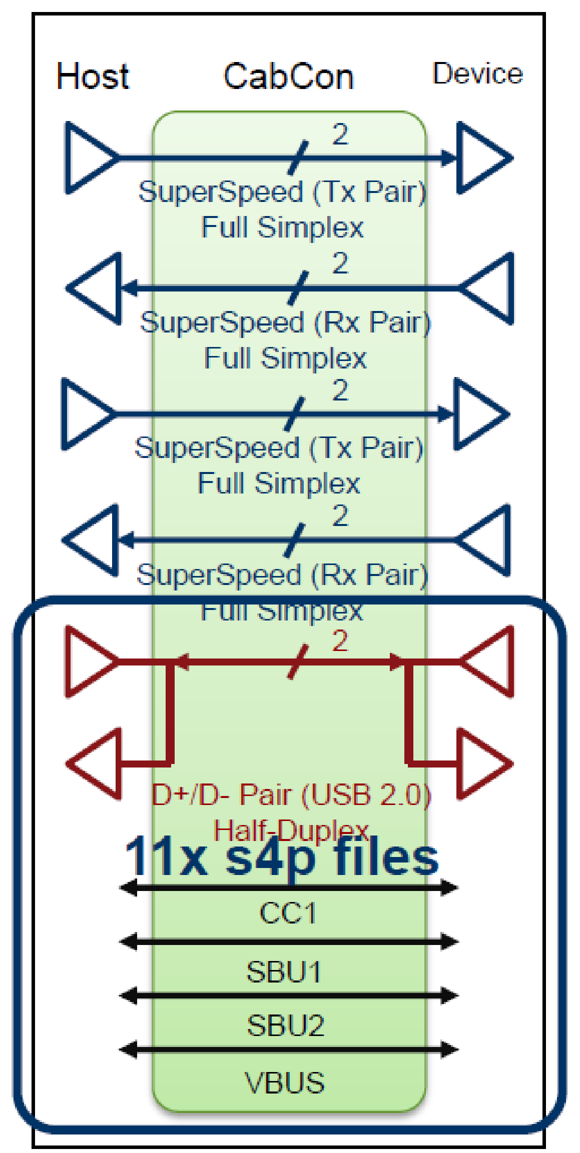
[Low Speed Signal] Characteristic Impedance



- Multiple reflections from impedance mismatches cause noise at the receiver. Therefore, the impedance profile provides an indication of multiple reflection induced noise.
- This test ensures that the CC and SBU_A & SBU_B wires lines have the proper impedance.

DUT Type	Limit
CC unshielded or shielded wires zCable_CC	32 Ω Min 93 Ω Max
SBU unshielded or shielded wires zCable_SBU	32 Ω Min 53 Ω Max

[Low Speed Signal] Crosstalk, VBUS Loop L/C, Coupling Factor

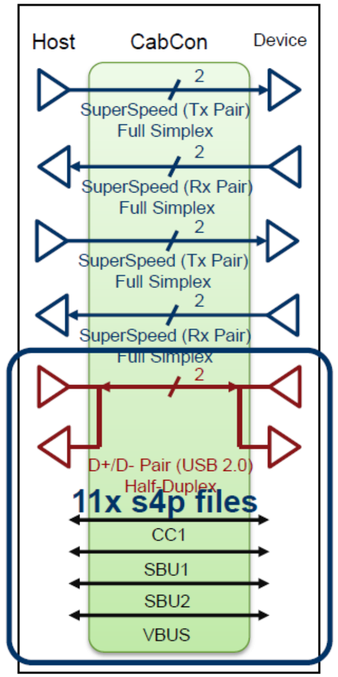


- Crosstalk, VBUS loop inductance, VBUS capacitance and coupling factor are calculated for low-speed signal and D+/D-pair.
- USB Type-C standard tool provided by USB-IF will do the pass/fail judgment based on measured Touchstone files. (11x s4p or 3x s8p or 1x s12p file)

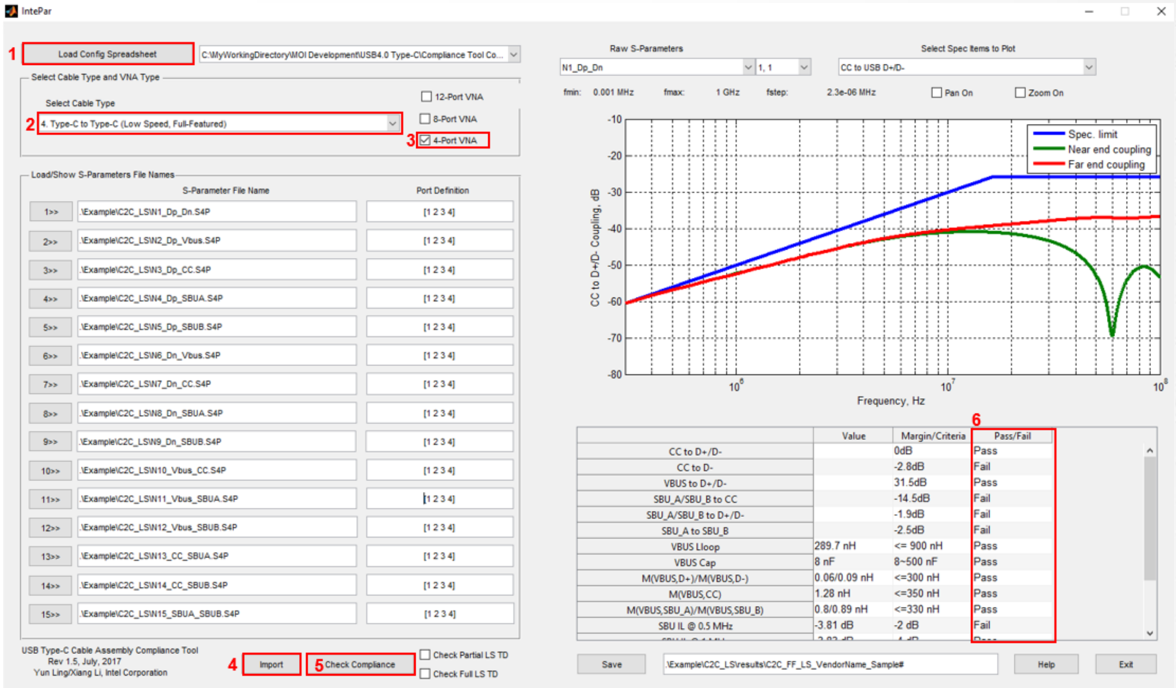
Test Parameters	Limit
Coupling between CC and Differential D+/D-	Refer to next slide for each test parameters
Single-ended Coupling between CC and D+/D-	
Coupling between VBUS and Differential D+/D-	
VBUS Loop Inductance, Coupling Factor, VBUS Capacitance	
Single-ended Coupling between SBU_A and SBU_B	
Single-ended Coupling between SBU_A/SBU_B and CC	
Coupling between SBU_A/SBU_B and Differential D+/D-	

Normative

[Low Speed Signal] Crosstalk, VBUS Loop L/C, Coupling Factor



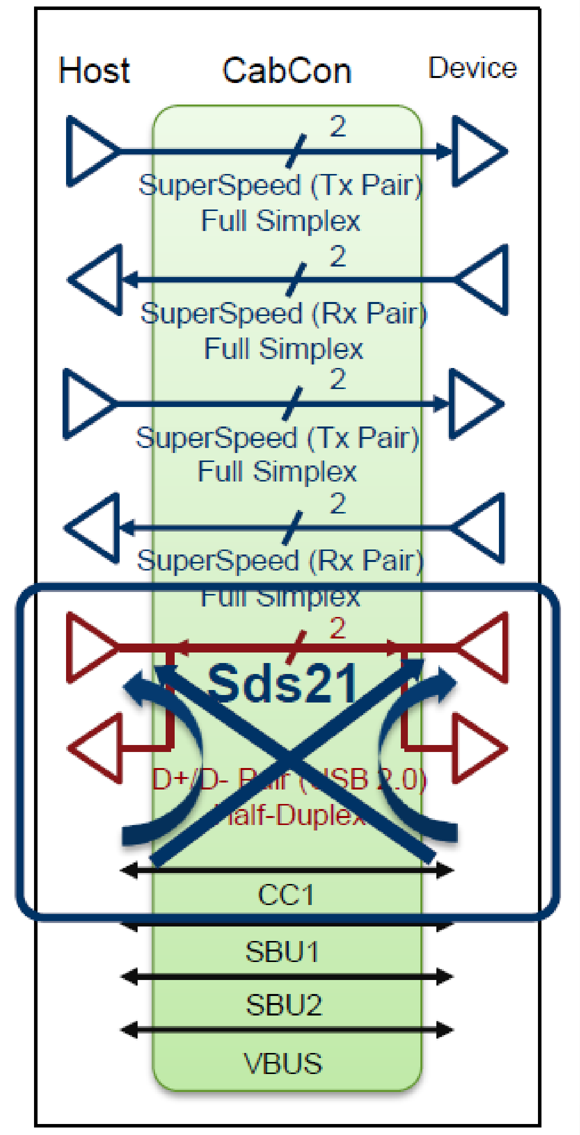
- 11x (*s4p) for low-speed full-feature
- 6x (*s4p) for low-speed charged-through



Touchstone S-parameter files (*s4p) for low-speed signal and D+/D- signal pair are saved and imported to the tool

IntePar tool: Import touchstone files to do the pass/fail judgement

[Low Speed Signal] Coupling between CC and D+/D−



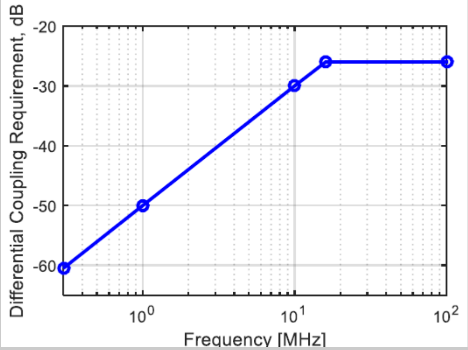
- Measure of coupling between CC and differential D+/D-.
- Coupling or crosstalk, both near-end and far-end, among the low-speed signals shall be controlled.

Table 3-25 Coupling Matrix for Low Speed Signals

Coupling Matrix	D− (SE)	D+/D− (DF)	VBUS	SBU_B/SBU_A (SE)
CC	FF, CT	FF, CT	FF, CT, CTVPD	FF
D+/D− (DF)	N/A	N/A	FF, CT	FF
SBU_A/SBU_B	N/A	FF	FF	FF

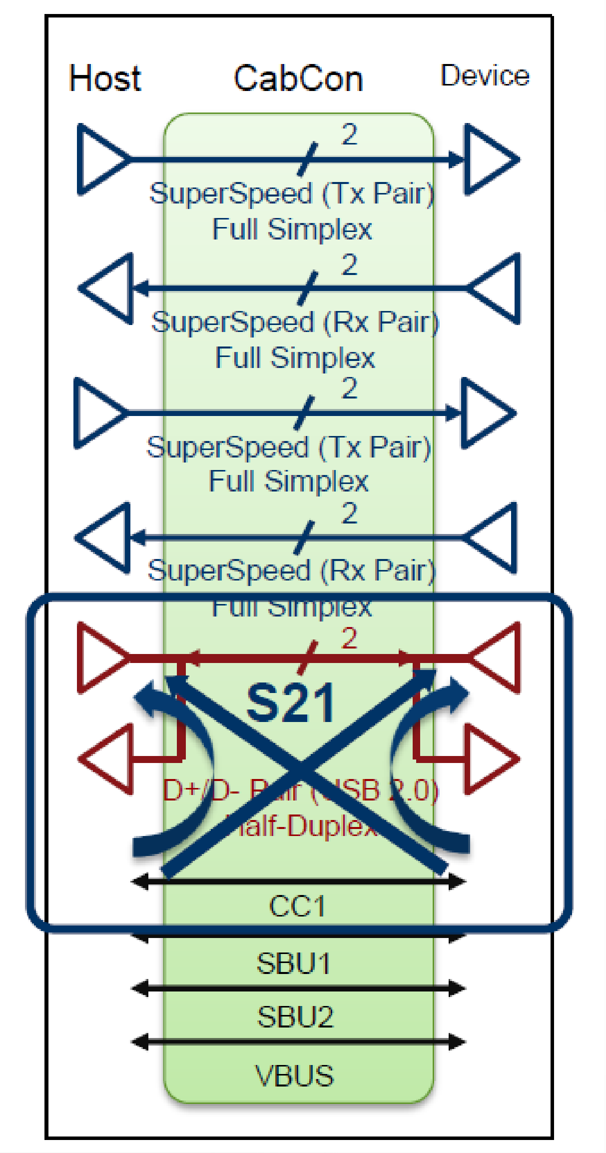
DF: Differential; FF: Full-featured cable; CT: Charge-through cable (including USB 2.0 function); CTVPD: Charge-Through VCONN-Powered USB Device.

DUT Type	Limit
Full-featured cable, charged-through cable	-60.5 dB @0.3 MHz -50 dB @1 MHz -30dB @10 MHz -26 dB @16 MHz -26 dB @100 MHz

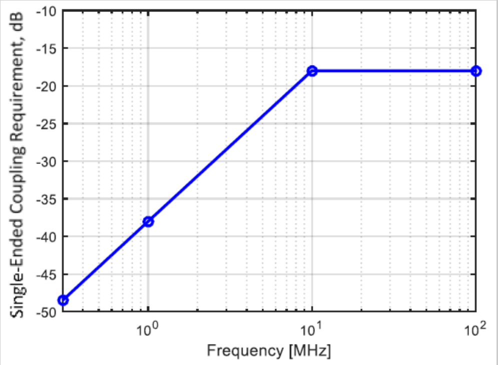
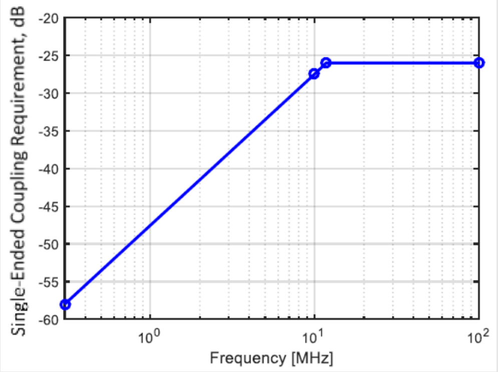


Normative

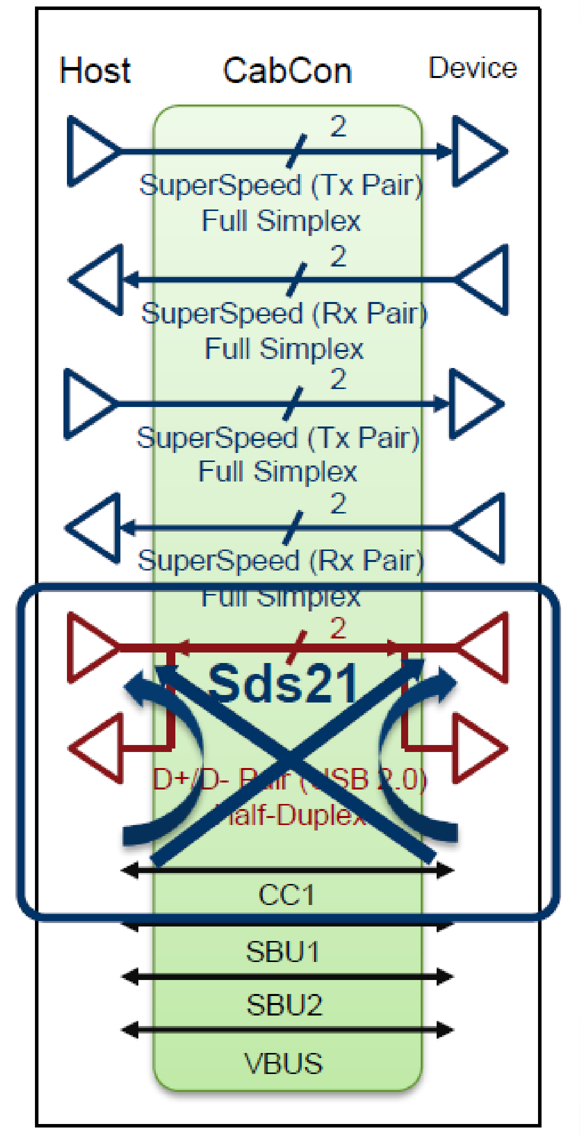
[Low Speed Signal] SE Coupling between the CC and D+/D−



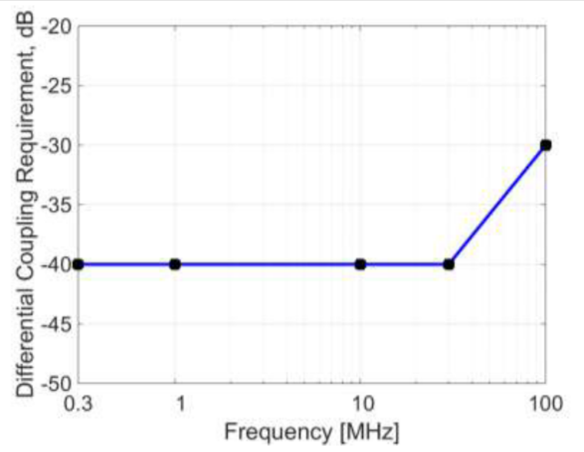
- Measure of single-ended coupling between CC and D+/D-.

DUT Type	Limit	
USB 2.0 Type-C cable	-48.5 dB @0.3 MHz -38 dB @1 MHz -18 dB @10 MHz -18 dB @100 MHz	
USB Full-Featured Type-C cable	-58 dB @0.3 MHz -27.5 dB @10 MHz -26 dB @11.8 MHz -26 dB @100 MHz	

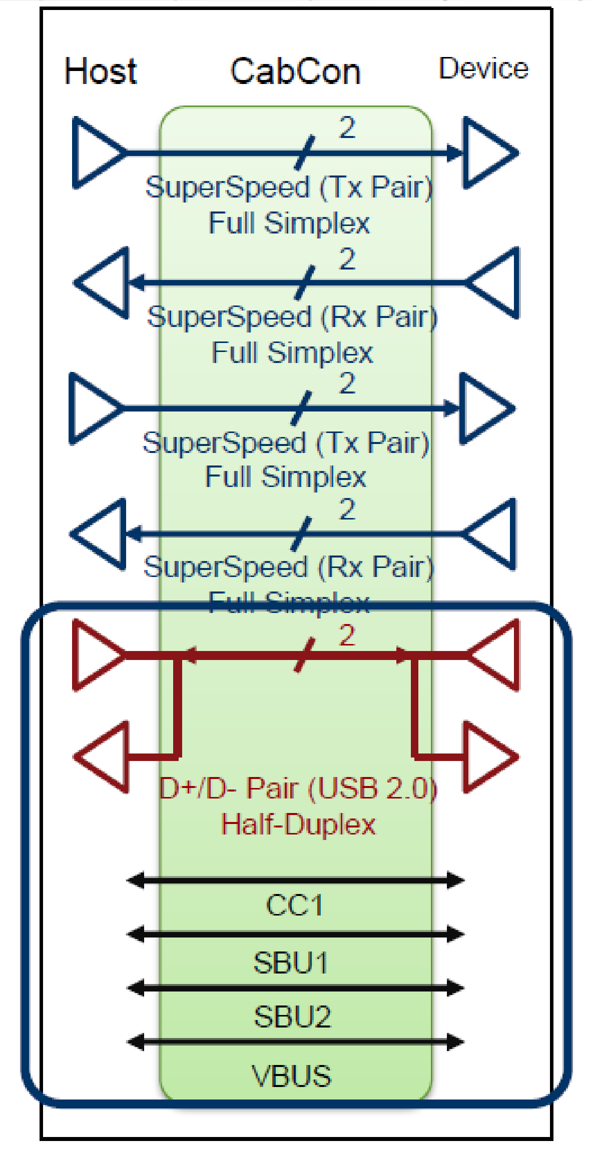
[Low Speed Signal] Coupling between V_{BUS} and Differential D+/D-



- Measure of coupling between VBUS and differential D+/D-.

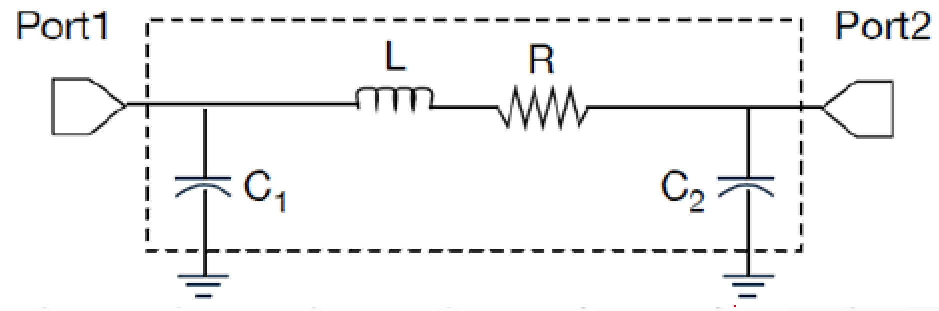
DUT Type	Limit	
Full-featured cable, charged-through cable	-40 dB @0.3MHz -40 dB @1 MHz -40 dB @30 MHz -30 dB @100 MHz	

[Low Speed Signal] VBUS Loop Inductance, Coupling Factor, VBUS Capacitance

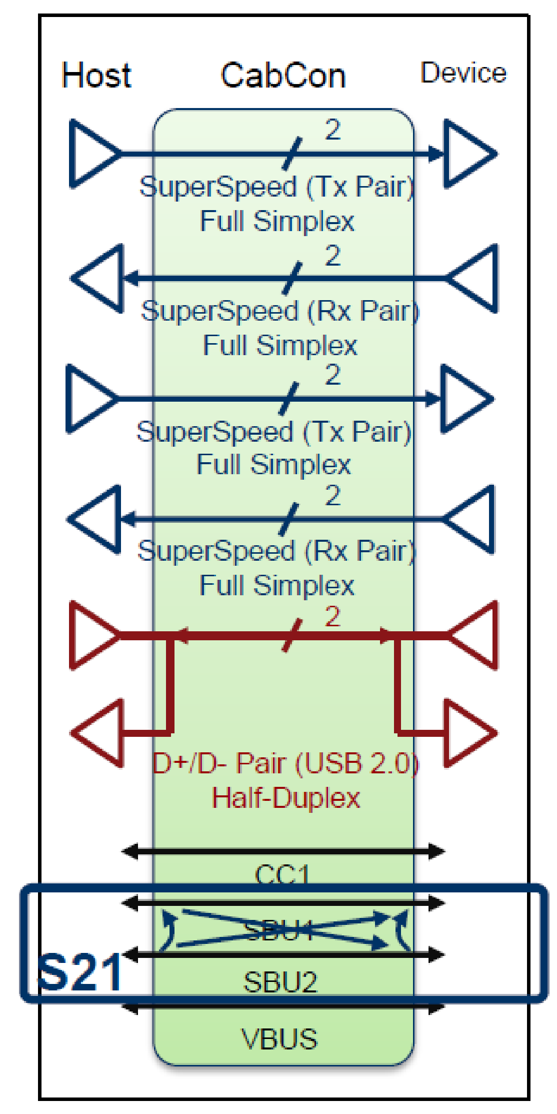


- The loop inductance of VBUS and its coupling factor to low- speed lines (CC, SBU_A/B, D+/D-) is controlled to limit noise induced on low speed signaling lines.
- For fully featured cables, the range of VBUS bypass capacitance shall be 8 nF up to 500 nF for high-speed return-path bypassing.

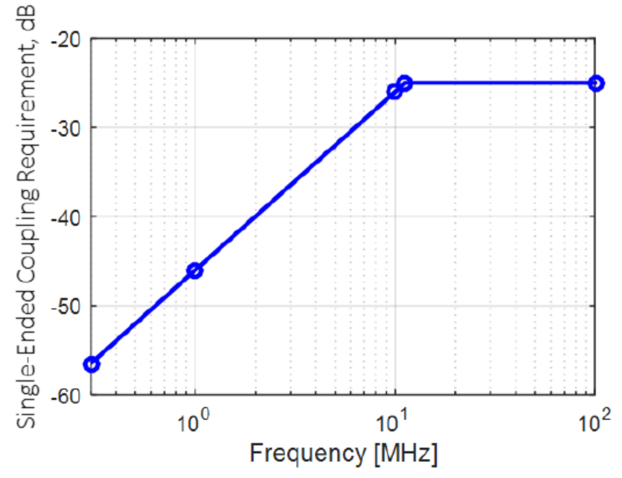
DUT Type	Limit
VBUS loop inductance	≤900nH
Mutual inductance coupling factor	≤0.3
VBUS capacitance	8 nF to 500 nF



[Low Speed Signal] SE Coupling between SBU_A and SBU_B

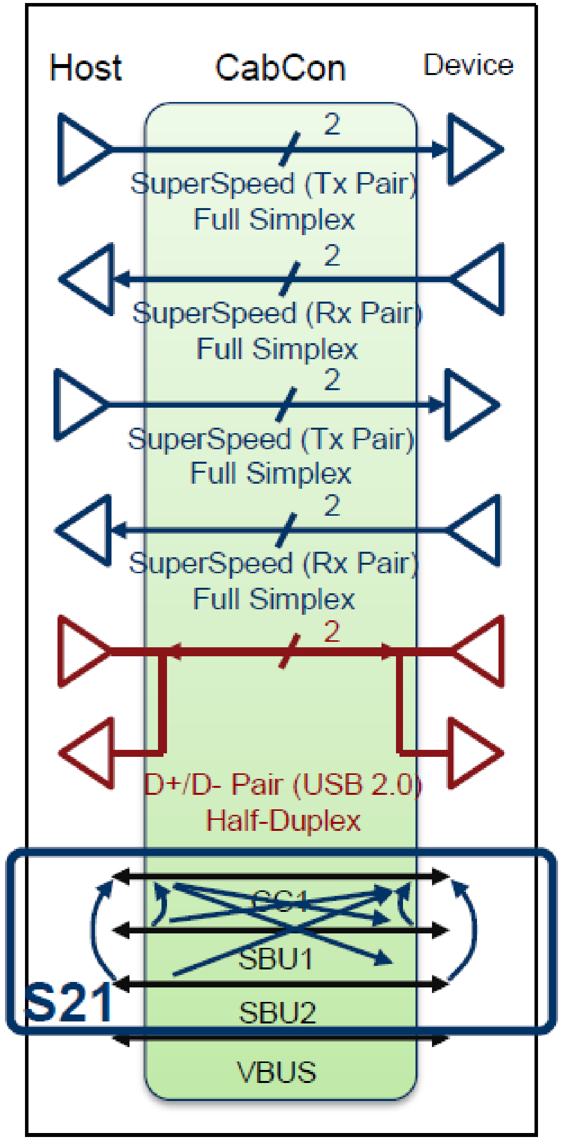


- Measure of single-ended coupling between SBU_A and SBU_B.

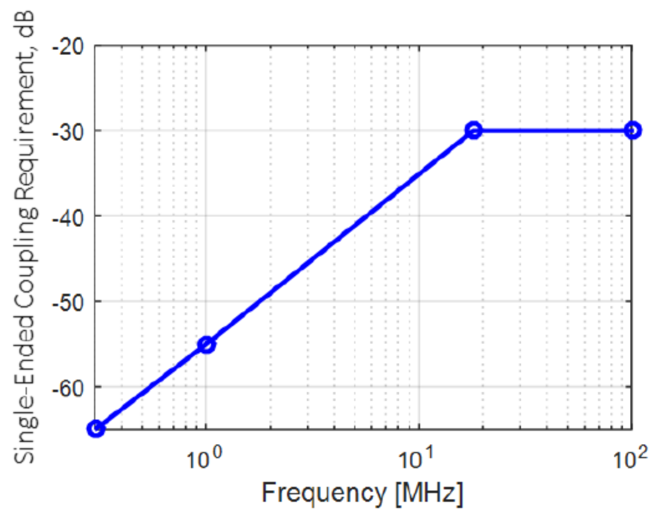
DUT Type	Limit
Full-featured cable	-56.5 dB @0.3 MHz -46 dB @1 MHz -26 dB @10 MHz -25 dB @11.2 MHz -25 dB @100 MHz 

Normative

[Low Speed Signal] SE Coupling between SBU_A/SBU_B and CC

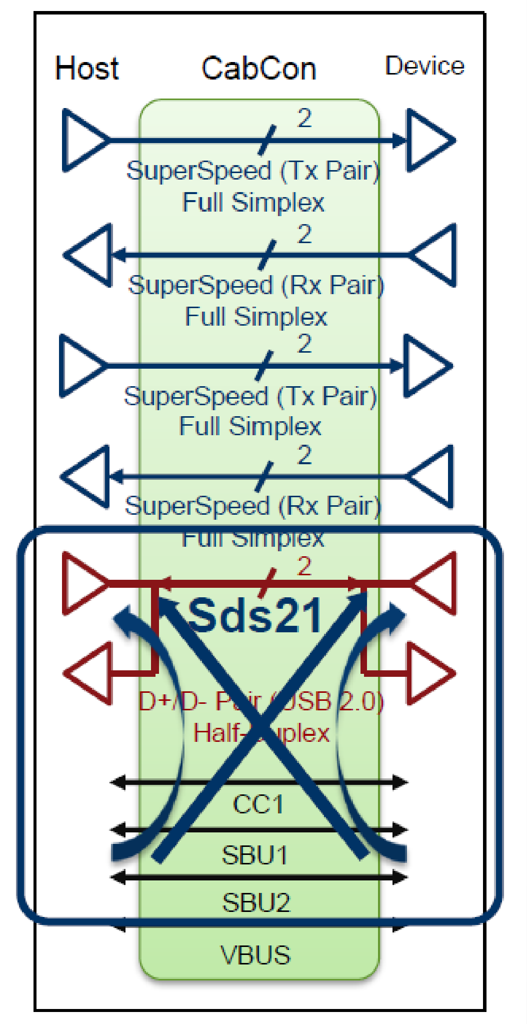


- Measure of single-ended coupling between SBU_A – CC and SBU_B - CC.

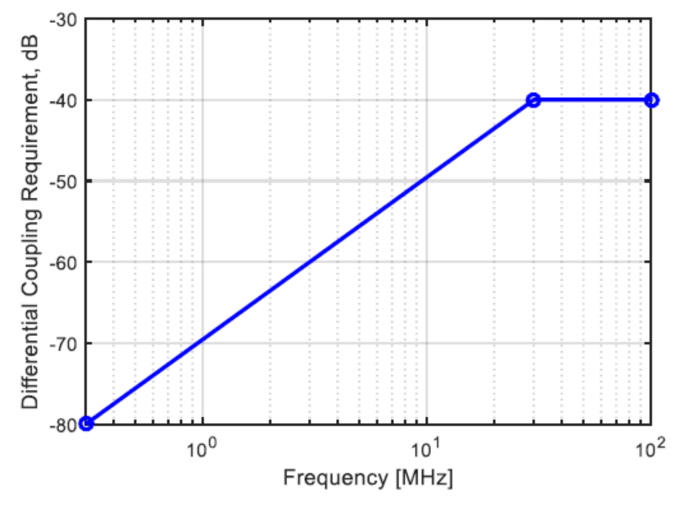
DUT Type	Limit	
Full-featured cable	-65 dB @0.3 MHz -55 dB @1 MHz -30 dB @18 MHz -30 dB @100 MHz	

KEYSIGHT TECHNOLOGIES

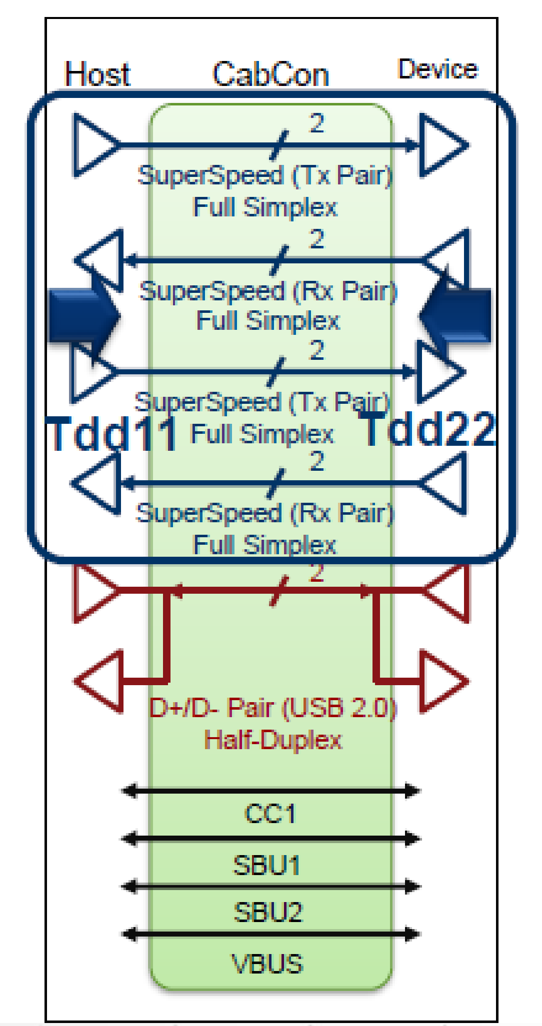
[Low Speed Signal] Coupling between SBU_A/SBU_B and Differential D+/D-



- Measure of coupling between SBU_A and differential D+/D-, and between SBU_B and differential D+/D-.

DUT Type	Limit
Full-featured cable	-80 dB @0.3 MHz -40 dB @30 MHz -40 dB @100 MHz 

[Raw Cable] Differential Impedance

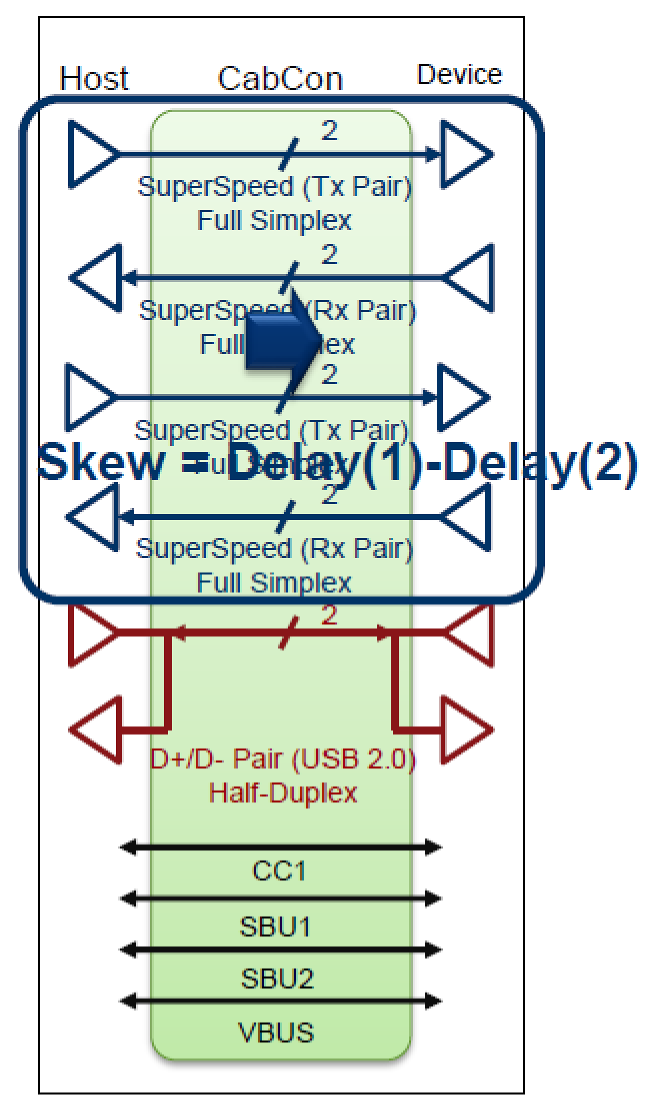


- Multiple reflections from impedance mismatches cause noise at the receiver. Therefore, the impedance profile provides an indication of multiple reflection induced noise.
- Impedance is the most used parameter but is an indirect measure of the signal arriving at the receiver.

DUT Type	Limit
Shielded Differential Pair (SDP)	90 Ω ± 5 Ω
Single-ended coaxial SS+ signal wires	45 Ω ± 3 Ω
Note: The impedance should be evaluated using a 200ps (10%-90%) rise time	

Informative

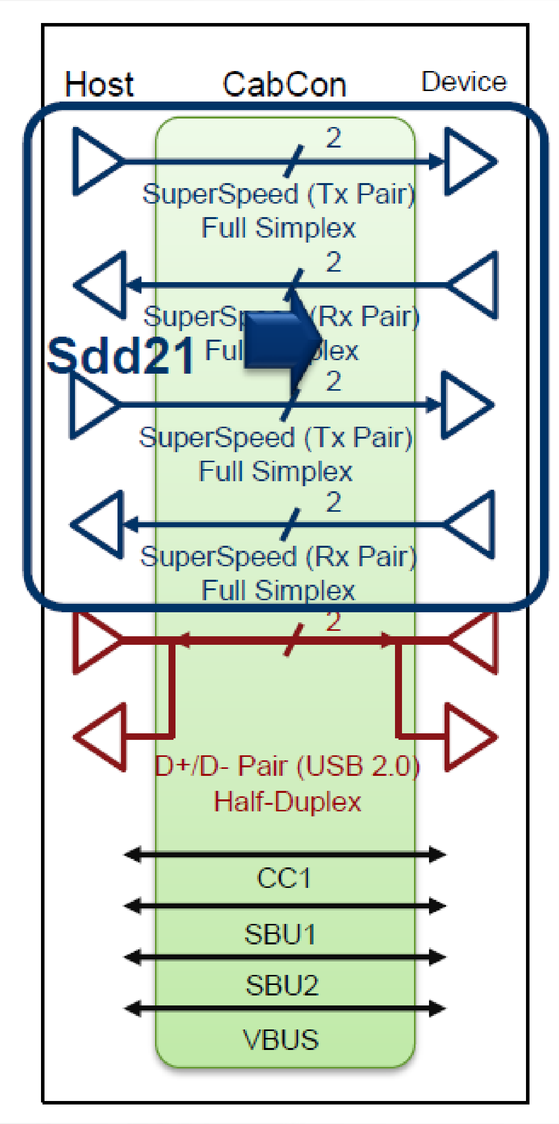
[Raw Cable] Intra-Pair Skew



- Intra-pair skew measurement ensures the signal on both SS+ Tx+ and Tx-lines (or Rx+ and Rx-lines) of a cable assembly arrive at the receiver at the same time.

DUT Type	Limit
Shielded Differential Pair (SDP)	< 10 ps/m
Note: It should be measured with a Time Domain Transmission (TDT) in a differential mode using a 200ps (10%-90%) rise time with a crossing at 50% of the input voltage	

[Raw Cable] Differential Insertion Loss



- Measure of frequency response that the differential signal sees as it propagates through the interconnect.
- Cable loss depends on wire gauges, plating and dielectric materials.

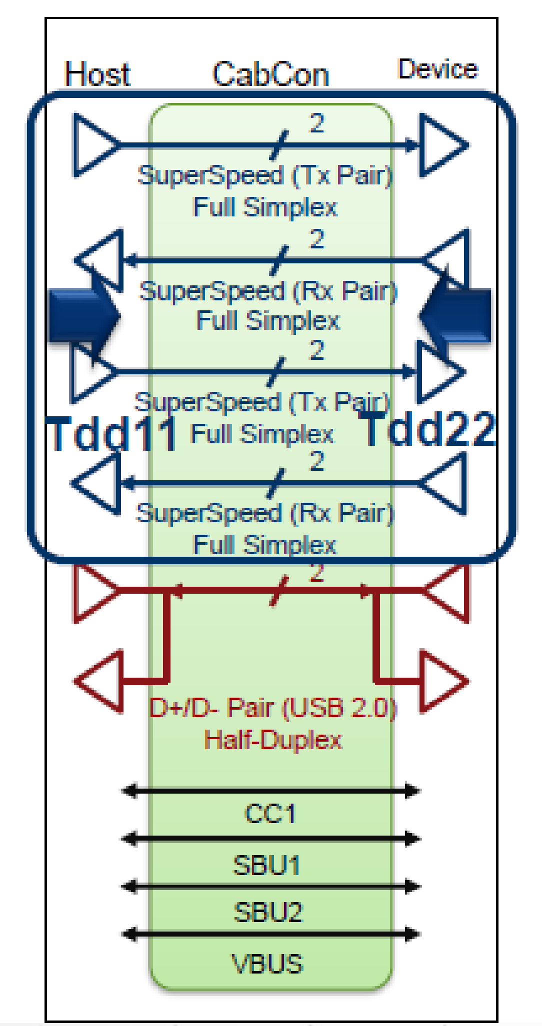
Frequency	34AWG	32AWG	30AWG	28AWG
0.625 GHz	-1.8 dB/m	-1.4 dB/m	-1.2 dB/m	-1.0 dB/m
1.25 GHz	-2.5 dB/m	-2.0 dB/m	-1.7 dB/m	-1.4 dB/m
2.50 GHz	-3.7 dB/m	-2.9 dB/m	-2.5 dB/m	-2.1 dB/m
5.00 GHz	-5.5 dB/m	-4.5 dB/m	-3.9 dB/m	-3.1 dB/m
7.50 GHz	-7.0 dB/m	-5.9 dB/m	-5.0 dB/m	-4.1 dB/m
10.00 GHz	-8.4 dB/m	-7.2 dB/m	-6.1 dB/m	-4.8 dB/m
12.50 GHz	-9.5 dB/m	-8.2 dB/m	-7.3 dB/m	-5.5 dB/m
15.00 GHz	-11.0 dB/m	-9.5 dB/m	-8.7 dB/m	-6.5 dB/m

Differential Insertion Loss Examples for TX/RX with Twisted Pair Construction

Frequency	34AWG	32AWG	30AWG	28AWG
0.625 GHz	-1.8 dB/m	-1.5 dB/m	-1.2 dB/m	-1.0 dB/m
1.25 GHz	-2.8 dB/m	-2.2 dB/m	-1.8 dB/m	-1.3 dB/m
2.50 GHz	-4.2 dB/m	-3.4 dB/m	-2.7 dB/m	-1.9 dB/m
5.00 GHz	-6.1 dB/m	-4.9 dB/m	-4.0 dB/m	-3.1 dB/m
7.50 GHz	-7.6 dB/m	-6.5 dB/m	-5.2 dB/m	-4.2 dB/m
10.0 GHz	-8.8 dB/m	-7.6 dB/m	-6.1 dB/m	-4.9 dB/m
12.5 GHz	-9.9 dB/m	-8.6 dB/m	-7.1 dB/m	-5.7 dB/m
15.0 GHz	-12.1 dB/m	-10.9 dB/m	-9.0 dB/m	-6.5 dB/m

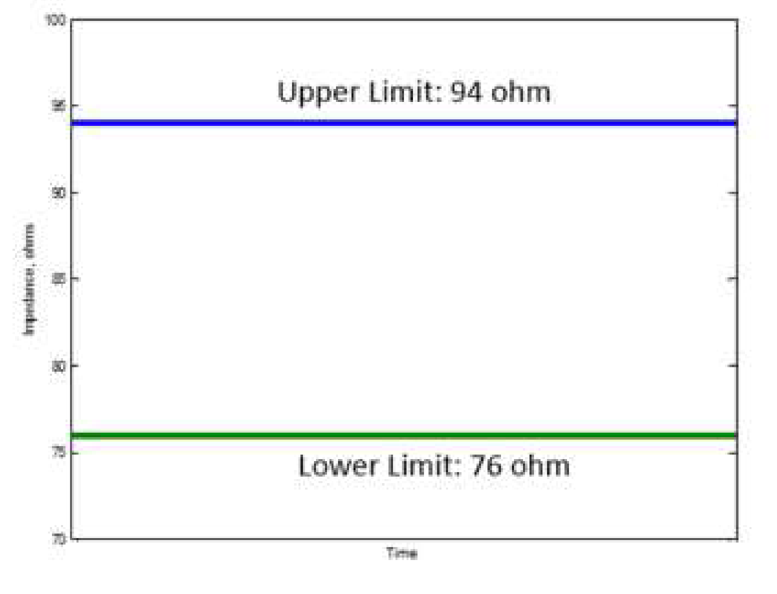
Differential Insertion Loss Examples for USB TX/RX with Coaxial Construction

[Mated Connector] Differential Impedance



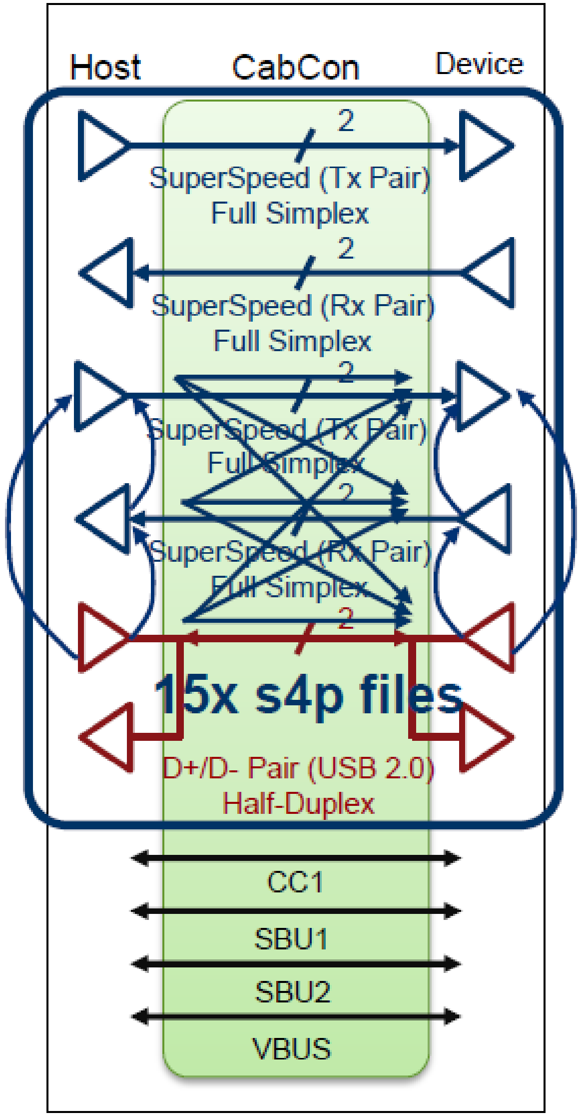
- Multiple reflections from impedance mismatches cause noise at the receiver. Therefore, the impedance profile provides an indication of multiple reflection induced noise.
- Impedance is the most used parameter but is an indirect measure of the signal arriving at the receiver.

DUT Type	Limit
Mated Connector for USB 3.2 Gen2 and USB4 Gen2	85 Ω ± 9 Ω
Note: The impedance should be evaluated using a 200ps (10%-90%) rise time.	



Informative

[Mated Connector] Channel Metrics

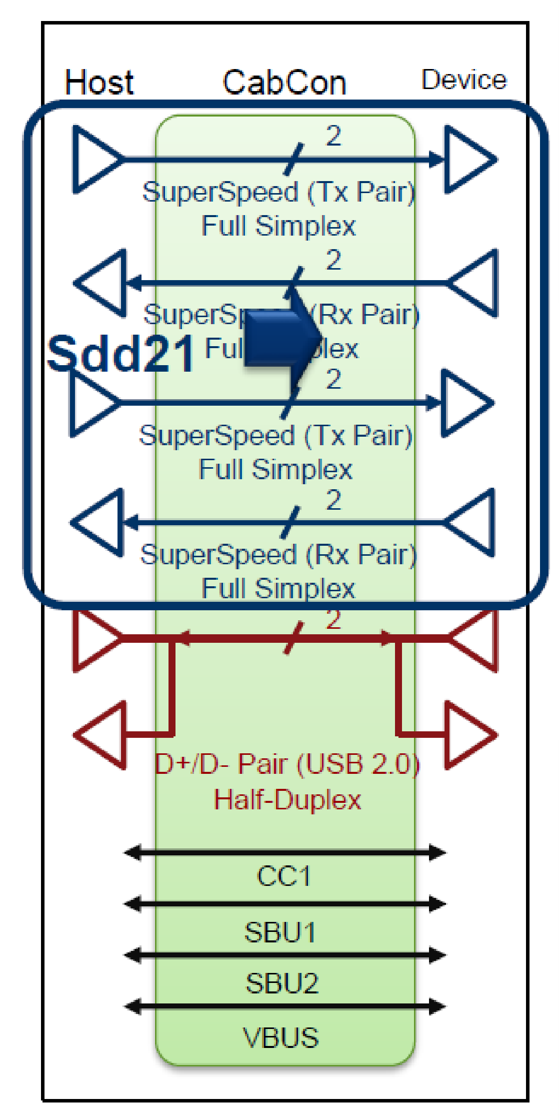


- Five parameters (ILfitatNq, IMR, IXT, IRL and Differential to Common-Mode Conversion) are calculated for SS+ pairs and D+/D-pair.
- USB Type-C standard tool provided by USB-IF will do the pass/fail judgment for five parameters based on measured Touchstone files.

DUT Type	Signal Integrity Compliance Requirements
USB4 Gen3 only (Normative)	ILfitatNq, IMR, IRL, INEXT and IFEXT, IDDXT_1NEXT+FEXT and, IDDXT_2NEXT, Differential-to -Common-Mode Conversion. (44x s4p or 10x s8p or 5x s12p or 2x s20p) USB-IF compliance tool: Get_iPar.exe https://compliance.usb.org/files/Ger_iPar_v0p91a_release.zip

Use "Comp_check_type" = 4 for connector, "Cable_Type" = 0 for passive cable and "case_number" = [1] for 4-ports measurements in the config file.

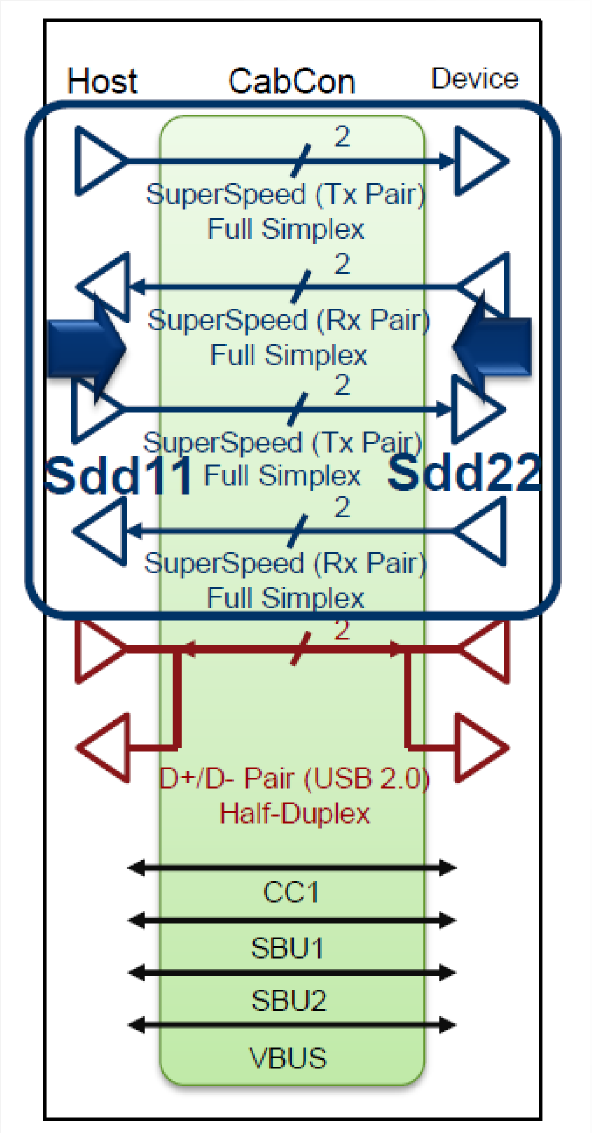
[Mated Connector] Differential Insertion Loss



- The IL is evaluated at the TX/RX Gen1, Gen2 and Gen3 generation Nyquist frequencies.
- The IL is **Normative for USB4 Gen 3** and Informative for USB 3.2 Gen2, USB4 Gen2.

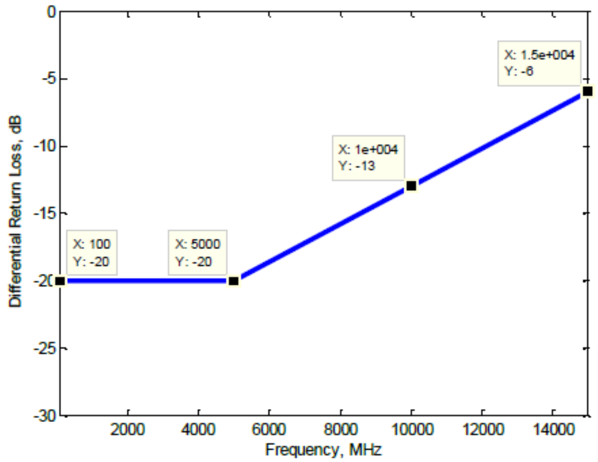
DUT Type	Limit
USB4 Gen 3 (Normative)	≥ −0.6 dB @ 2.5 GHz ≥ −0.8 dB @ 5.0 GHz ≥ −1.0 dB @ 10 GHz ≥ −1.25 dB @ 12.5 GHz ≥ −1.5 dB @ 15 GHz
USB 3.2 Gen2, USB4 Gen2 (Informative)	≥ −0.6 dB @ 2.5 GHz ≥ −0.8 dB @ 5.0 GHz ≥ −1.0 dB @ 10 GHz

[Mated Connector] Differential Return Loss

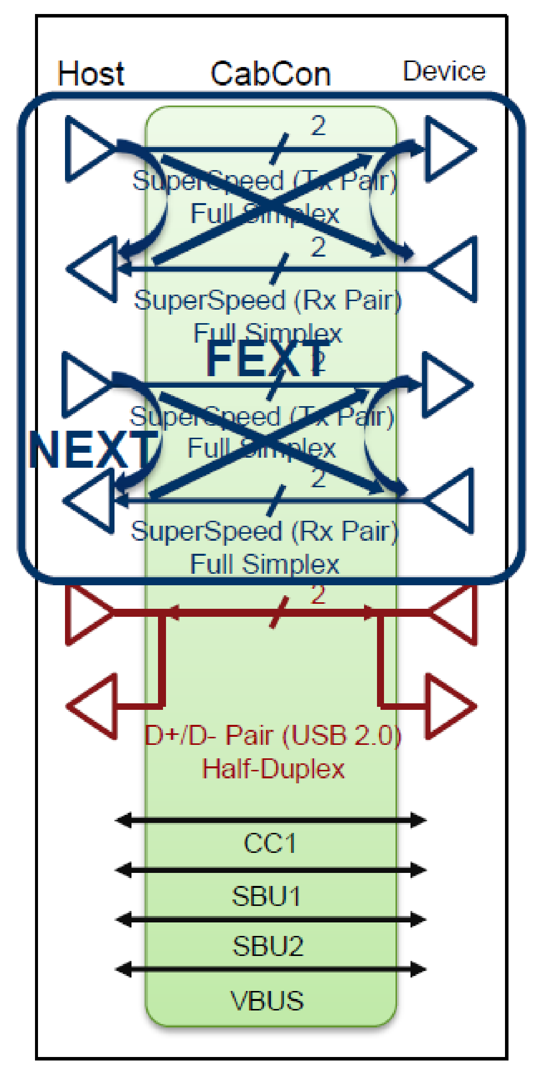


- Measure of frequency response that the differential signal sees as it reflected through the interconnect

DUT Type	Limit
USB4 Gen 3 (Normative) USB 3.2 Gen2 and USB4 Gen2 (Informative)	≥-20 dB @100 MHz ≥-20 dB @5 GHz ≥-13 dB @10 GHz ≥-6 dB @15 GHz



[Mated Connector] Differential NEXT & FEXT between SS Signal

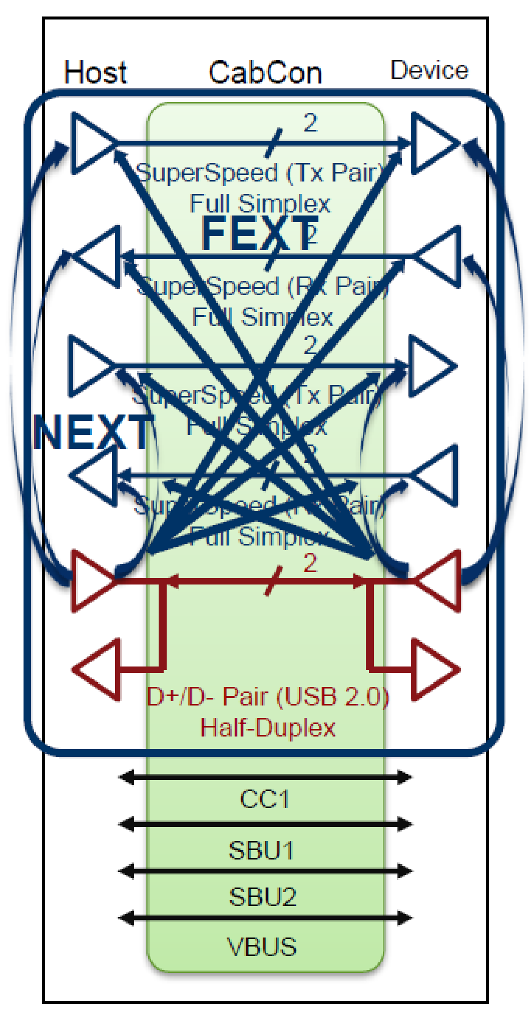


- Measure of coupling between the SS differential pairs (Tx/Rx pair).

DUT Type	Limit
USB4 Gen 3 (Normative) USB 3.2 Gen2 and USB4 Gen2 (Informative)	≥-40 dB @100 MHz ≥-40 dB @5 GHz ≥-36 dB @10 GHz ≥-30 dB @15 GHz

Informative

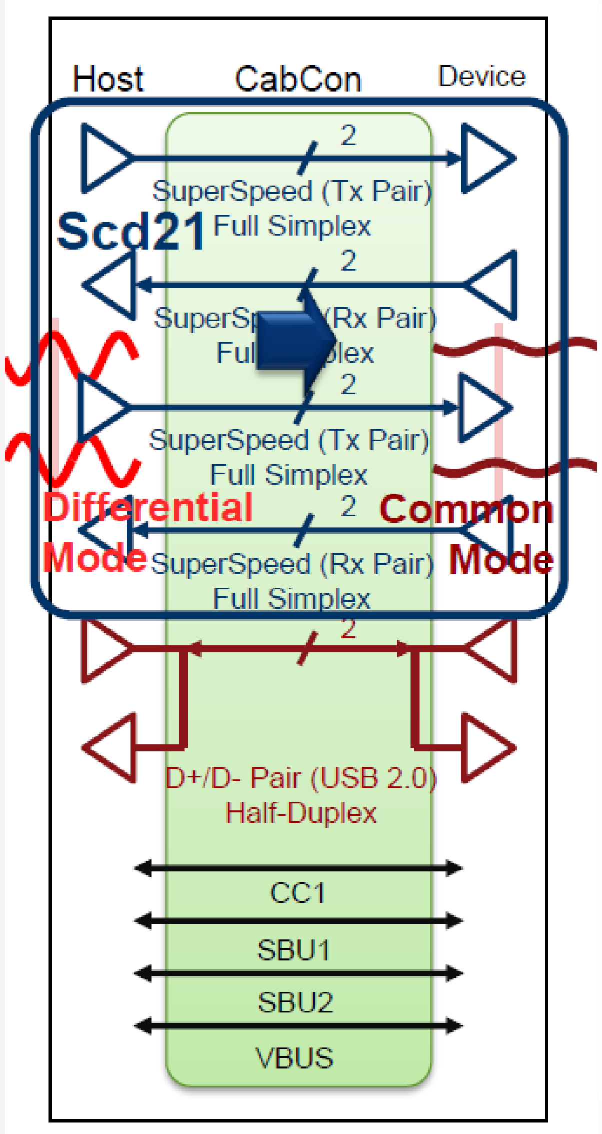
[Mated Connector] Differential NEXT & FEXT between D+/D- and SS Signal Pairs



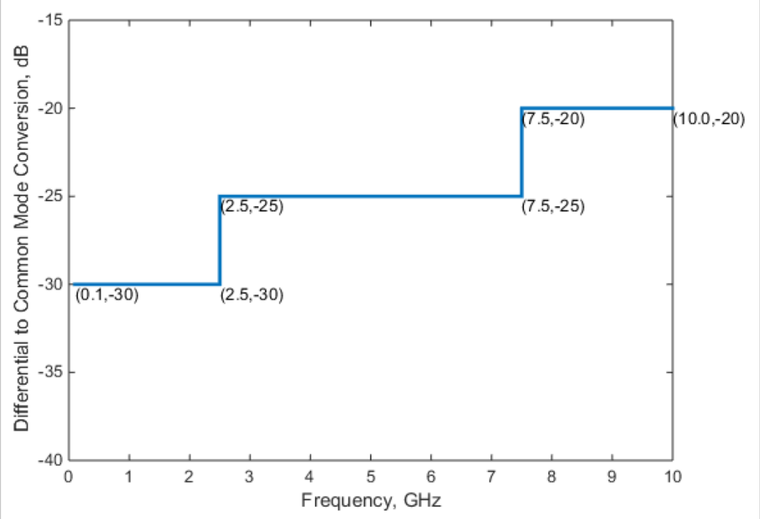
- Measure of coupling between D+/D- and the SS differential pairs (Tx/Rx pair).

DUT Type	Limit
USB4 Gen 3 (Normative)	≥-40 dB @100 MHz ≥-40 dB @5 GHz ≥-36 dB @10 GHz ≥-30 dB @15 GHz
USB 3.2 Gen2 and USB4 Gen2 (Informative)	≥-40 dB @100 MHz ≥-40 dB @5 GHz ≥-36 dB @7.5 GHz

[Mated Connector] Differential to Common-Mode Conversion

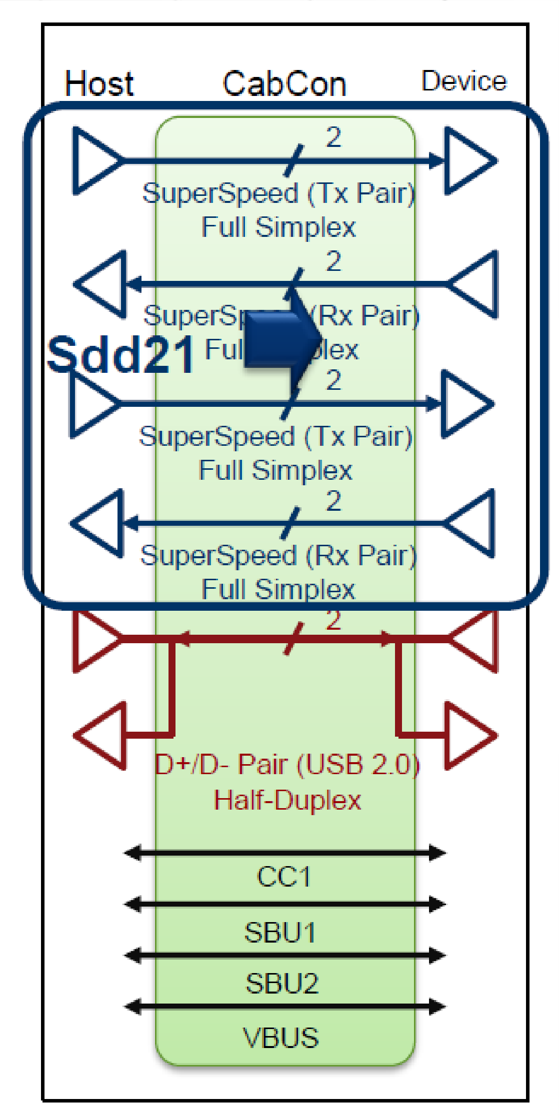


- Common-mode current is directly responsible for EMI and Scd21 is a measure of EMI generation.
- Main purpose of this requirement is to limit EMI emission.

DUT Type	Limit
USB4 Gen 3 (Normative) USB 3.2 Gen2 and USB4 Gen2 (Informative)	≥-30 dB @100 MHz ≥-30 dB @2.5 GHz ≥-25 dB @7.5 GHz ≥-20 dB @10 GHz 

Informative

Differential Insertion Loss

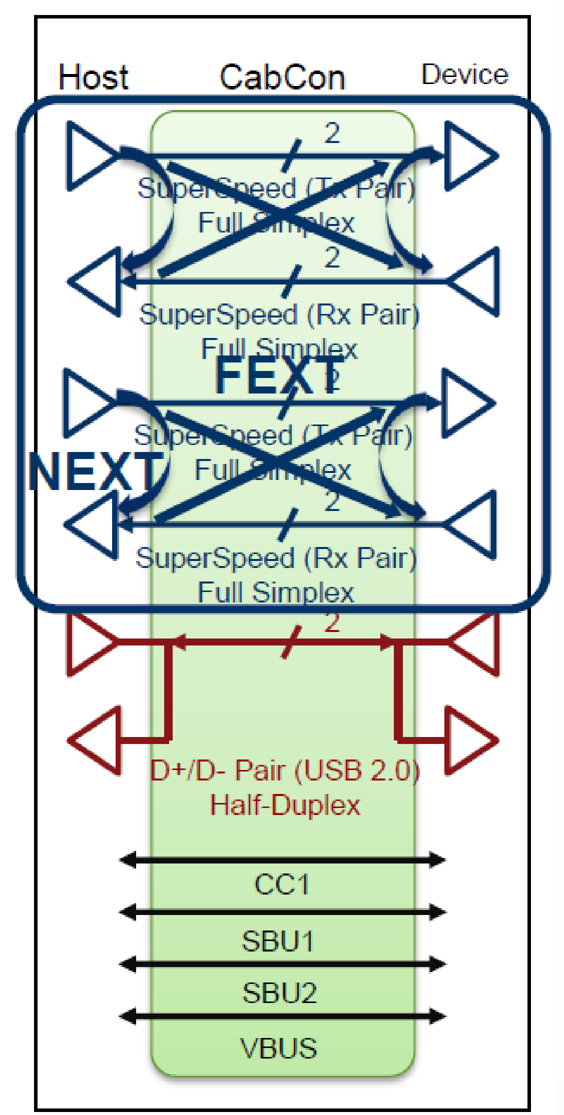


- Measure of frequency response that the differential signal sees as it propagates through the interconnect

DUT Type	Limit
Type-C to Type-C Cable USB4 Gen3	≥-1.00 dB @100 MHz ≥-4.20 dB @2.5 GHz ≥-6.00 dB @5 GHz ≥-7.5.00 dB @10 GHz ≥-9.3.00 dB @12 GHz ≥-11.00 dB @15 GHz
Type-C to Type-C Cable USB3.2 Gen2 and USB4 Gen2	≥-2.00 dB @100 MHz ≥-4.00 dB @2.5 GHz ≥-6.00 dB @5 GHz ≥-11.00 dB @10 GHz ≥-20.00 dB @15 GHz
Type-C to Legacy Cable	≥-2 dB @100 MHz ≥-4 dB @2.5 GHz ≥-3.5 dB @2.5 GHz (USB Type-C to USB 3.1 Standard-A) ≥-6 dB @5 GHz
Type-C to Legacy Adapter	≥ −2.4 dB to 2.5 GHz, ≥ −3.5 dB to 5 GHz

Informative

Differential NEXT & FEXT between SS Signal

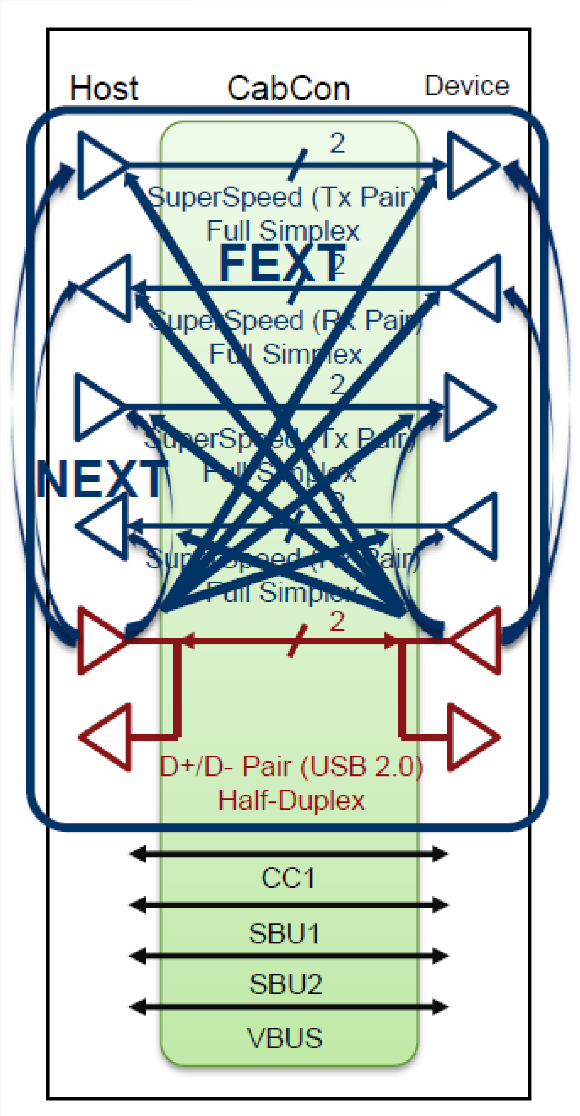


- Measure of coupling between the SS differential pairs (Tx/Rx pair).

DUT Type	Limit
Type-C to Type-C Cable	≤-40 dB @100 MHz ≤-40 dB @5 GHz ≤-35 dB @10 GHz ≤-32 dB @15 GHz
Type-C to Legacy Cable (NEXT only)	≤-34 dB to 5 GHz
Type-C to Legacy Adapter (NEXT only)	≤-40 dB to 2.5 GHz ≤-34 dB to 5 GHz

Informative

Differential NEXT & FEXT between D+/D- and SS Signal



- Measure of coupling between D+/D- and SS differential pairs (Tx/Rx pair).

DUT Type	Limit
Type-C to Type-C Cable	≤-35 dB @100 MHz ≤-35 dB @5 GHz ≤-30 dB @7.5 GHz
Type-C to Legacy Cable	≤-30 dB to 5 GHz
Type-C to Legacy Adapter	≤-30 dB to 2.5 GHz

KEYSIGHT TECHNOLOGIES

ENA Option TDR Compliance Test Solution

Certified MOIs available at: www.keysight.com/find/ena-tdr_compliance

Cable/Connector/Interconnect

- SuperSpeed USB: Time & Frequency
- HDMI: Frequency
- Serial ATA: Time & Frequency
- DisplayPort: Time & Frequency
- 100BASE-TX: Time & Frequency
- 10GBASE-T: Time & Frequency
- 10GBASE-KR/40GBASE-KR4: Time & Frequency
- MHL: Time & Frequency
- PCI Express: Time
- BroadR-Reach *: Time & Frequency

Transmitter/Receiver Impedance (Hot TDR/RL)

- HDMI: Time
- Serial ATA: Time & Frequency
- MIPI alliance: Time & Frequency
- MHL: Time & Frequency
- 10GBASE-KR/40GBASE-KR4: Frequency
- PCI Express: Frequency
- Thunderbolt *: Time & Frequency
- SD *: Frequency
- CFA CompactFlash *: Time & Frequency

USB Type-C Cable/Connector Compliance Test Solution

Enhanced TDR Cable/Connector Compliance Testing Solution is ….

- One-box solution which provides complete characterization of high-speed digital interconnects (time domain, frequency domain, eye diagram)
- Similar look-and-feel to traditional TDR scopes, providing simple and intuitive operation even for users unfamiliar to VNAs and S-parameters
- Adopted by test labs worldwide

Web Resources

www.keysight.com/find/ena-tdr_compliance

www.keysight.com/find/usb-vna

www.keysight.com/find/na

www.keysight.com/find/vnasoftware

www.keysight.com/find/ecal

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