APPLICATION NOTE

How to Ensure Interoperability and Compliance of USB Type-C Cables and Connectors

Keysight and USB Type-C: Create a faster path to done

Overview

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

- Dynamic power and transmission of USB 2.0 with other protocols
- Key interface for many new and future devices
- Backward compatibility
- Reversibility enables ease-of-use

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

This application note is one in a series of five covering the challenges and solutions for USB Type-C design and test.
- Cable and connector
- Power delivery
- Transmitter/receiver
- Simulation-measurement correlation
- Alternate Mode (ALT) (DisplayPort, Thunderbolt, MHL)

USB Type-C cable and connectors

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

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

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

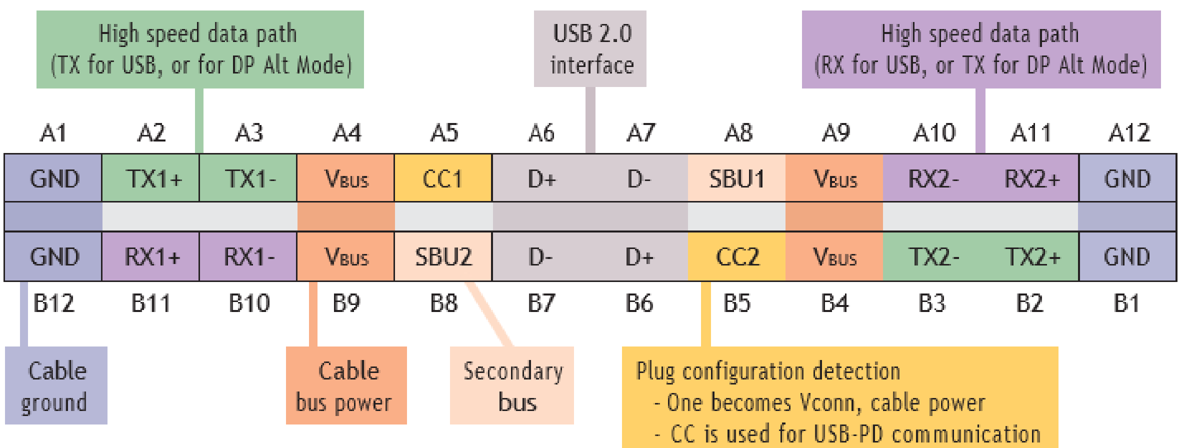


Figure 1. USB Type-C pin out. Notice the symmetrical and reversible structure

The USB Type-C cable and connector (the channel) provides not only backward USB compatibility, but also increased functionality for power management and data transmission. USB Type-C power delivery provides up to 20 volts, 5 amps and 100 watts for dynamic power and charging of different devices. The transmitter/receiver (Tx/Rx) pairs can be used for USB or “guest protocols” such as DisplayPort, MHL, or Thunderbolt data transfer, making it possible to transfer high-speed data, video and audio signals in addition to USB. USB Type-C data transfer rates are up to 40 Gbps (USB 4.0 Gen3 and Thunderbolt-3 Gen3), with the ability to achieve 80 Gbps in the future. These new capabilities create a greater challenge for design and test engineers who are working to ensure the interoperability of their USB channel and devices by performing USB-IF standard conformance tests.

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

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

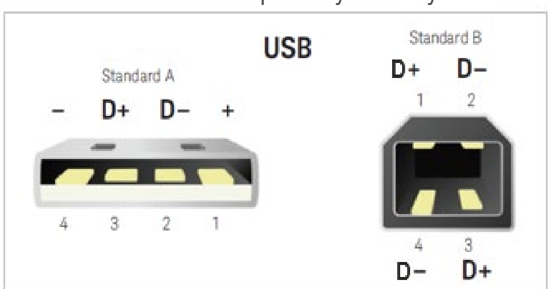
Pin functionality overview

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

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

Two differential pairs (D+/D-)

USB 2.0 data bus are dedicated pin to ensure that USB 2.0 backward compatibility is always available.



Four power/ground pairs (V_{bus}), (GND)

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

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

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

Two secondary bus pins (SBU1, SBU2)

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

USB Type-C cable and connector test challenges

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

According to the USB-IF, USB Type-C must be backward compatible and supports previous versions of USB specification signals (USB 2.0 and USB 3.x). Along with this backward compatibility requirement, the USB-IF has defined following USB Type-C cables, both with Type-C plugs at each end:

- The full-featured Type-C cable with a full-featured Type-C plug at both end for USB4, USB 3.2, and full-featured applications.
- USB 2.0 Type-C cable with a USB 2.0 Type-C plug at both ends (typically for mobile charging).
- Captive cable with either a USB full-featured Type-C plug or USB 2.0 Type-C plus at one end.
- USB4 and USB3.2 active cable.

Rather than specified cable lengths for electrical compliance channels, USB4, USB 3.x, and USB Type-C have specified channel loss, which plays a key role in ensuring interoperability of USB hosts and devices. An example would be a two-meter cable which is required to have no more than 7 dB of insertion loss. With a 20 dB SuperSpeed Gen 1 limit, only 13 dB are remaining to split between the host and device.

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

Managing EMI and RFI levels from the cable assembly

A newer Type-C receptacle design provides more grounding and better overall shielding to prevent RF leakage and has reduced USB4/USB 3.2 RFI problems. New specification standards were also added for Type-C to manage cable radiation by requiring cable shielding effectiveness measurements.

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

Removing test fixture effects

Accurate electrical characterization of the Type-C interconnects over a wide range of frequencies is critical for high-speed bus design. With the increased data rate of 20/40 Gbps, characterization becomes more challenging. Electrical characterization of high-speed interconnects is usually done in the frequency domain using a vector network analyzer (VNA). A fixture is used to connect from the device under test (DUT) to the VNA. A complete removal of the test fixture is crucial to prevent fixture artifacts from affecting test results, especially at higher frequencies. Fixture removal cab be achieved by calibration or de-embedding (automatic fixture removal) processes and the quality of the instrumentation and process used is reflected in the resulting measurement accuracy.

The Automatic Fixture Removal (AFR) technique dramatically reduces the complexity of directly measuring the S-parameters of the fixture. An essential element to the AFR technique is leveraging signal processing in the time domain to extract the unique values of S-parameters. With these, each element of the S-parameters of each fixture can be uniquely extracted. The intuitive user interface of AFR application transforms this normally complex error correction algorithm into a simple task.

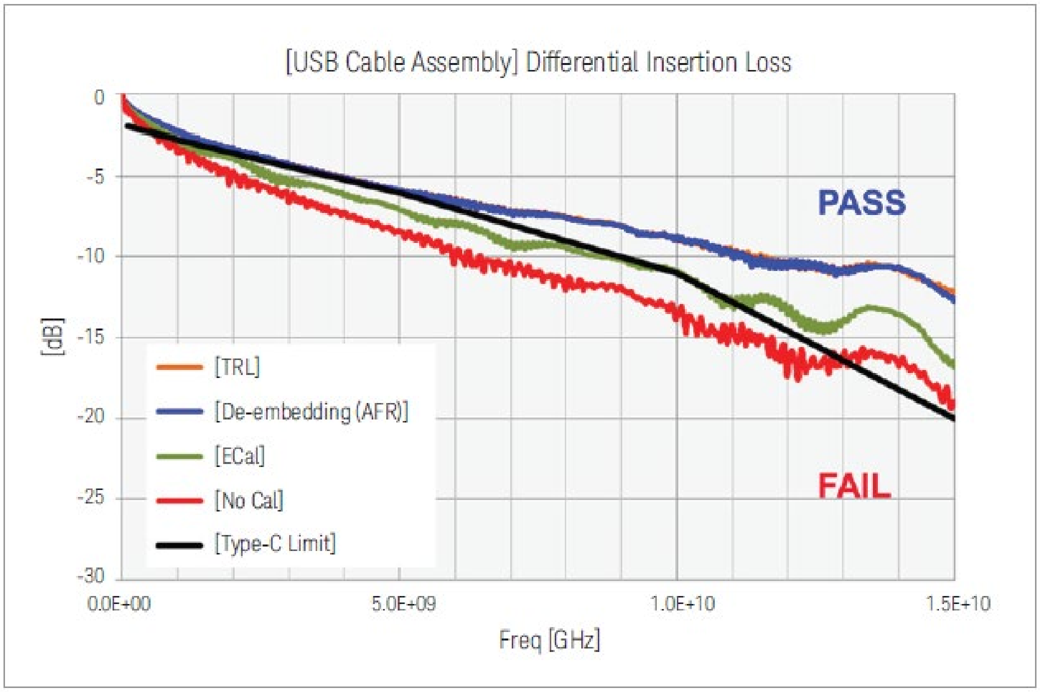


Figure 3. Significant loss at higher frequencies requires a more rigorous approach to removing fixture effects to measure the true performance of the device.

Effects on channel response

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

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

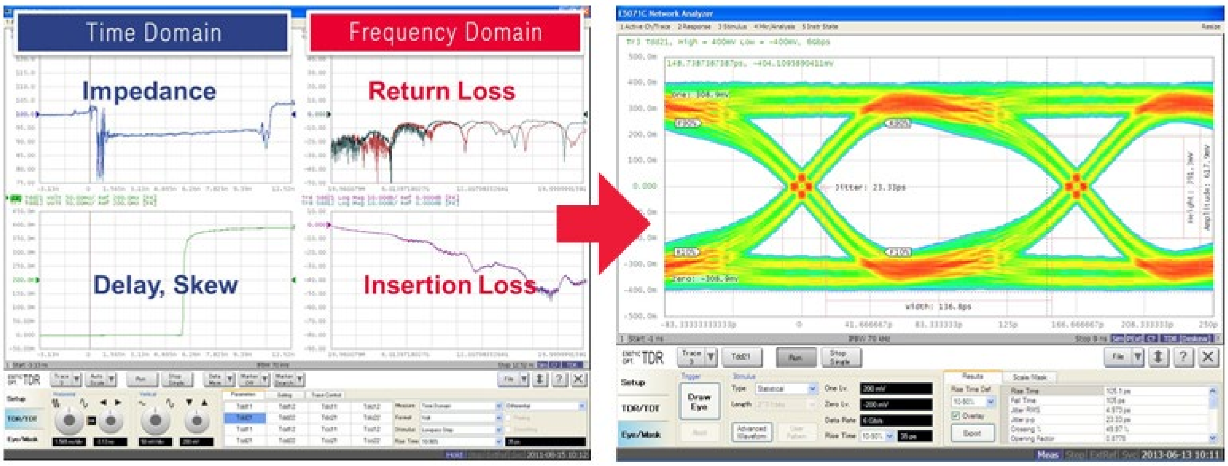


Figure 4. Channel response is affected by many features in the channel (loss, reflection, crosstalk, mode conversion) and requires a new measurement methodology involving a shift from traditional parametric to stressed eye testing (channel metrics/margin).

Introduction of USB-IF compliance test tools

USB-IF introduced new test requirements for USB4 Gen3 cable's Channel Operating Margin (COM) and integrated crosstalk that required a new Matlab based compliance test tool (Get_iPar.exe) to compile the 44-sets of S-parameters for compliance verdict judgement. User needs to manually setup the tool's configuration file to compile and verify pass/fail verdict. Other cable types on USB4 Gen2 and USB 3.x also required similar Matlab test tool (IntePar.exe) with 30-sets of S4P for high-speed signal test result compilation.

Conventional way of USB Type-C cable test using 4-port VNA and follows Method of Implementation (MOI) document required numerous port re-connections to complete the full S4P measurements. These manual operations may lead to longer test time (3 to 5 hours for one high-speed signal test) and prone to unnecessary human errors which making compliance test become inefficient and more challenging.

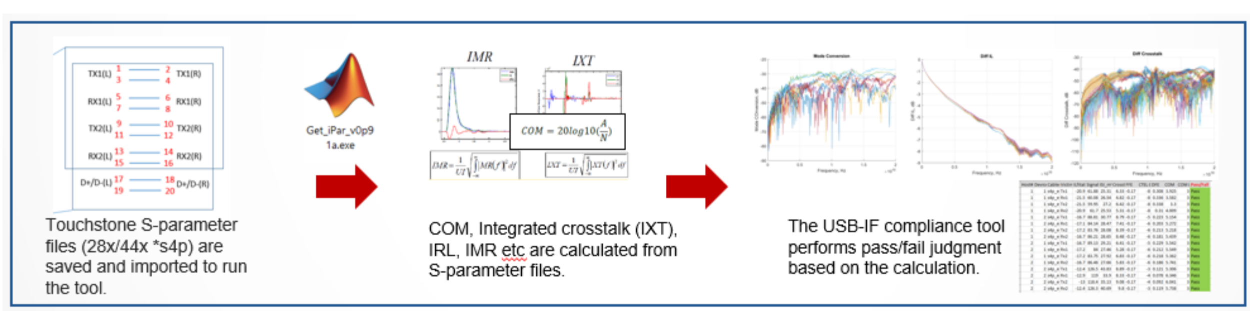


Figure 5. Manual steps of executing USB-IF compliance test tool (Get_iPar) for USB4 Gen3 high-speed signal test (44-sets S4P) and USB4 LRD active cable test (28-sets S4P).

Keysight High-Speed Digital Interconnectors Test Solutions

Option 1: One-box solution using 4-Ports VNA

Traditional cable/connector compliance tests used a vector network analyzer (VNA) for the frequency domain analysis, and a TDR (time domain reflectometry) oscilloscope for time domain analysis. Keysight ENA series network analyzer with enhanced time domain analysis (option TDR) application provides one-box solution that measures all the compliance parameters.

- Supports Method of Implementation (MOI), a step-by-step procedure for specified parameter measurement upon the release of USB-IF compliance documentation.
- Provides state file with pre-defined measurement parameters and test mask limits based on USB-IF compliance test specification for each support VNA model.
- The USB Type-C Cable & Connector Assembly MOI can be found at: http://www.keysight.com/find/ena-tdr_usbtype-c-cabcon

In additional to USB, the enhanced TDR (E-TDR) application is certified to support various high-speed digital (HSD) interconnects standards. Test MOI procedures and state file are available for a free download at

www.keysight.com/find/ena-tdr_compliance

Keysight E5080B ENA Series network analyzer is an ideal solution for manufacturing and R&D engineers evaluating RF components and circuits for frequency ranges up to 53 GHz.

Recommended configuration

Items	Description	Quantity
Network Analyzer	Min. 4-ports, 20 GHz is recommended as USB4/Type-C cable/connector requires measurements up to 20 GHz (Low-speed signal test required start frequency at 300 kHz) • E5080B-4K0: 4-port test set, 9 kHz to 20 GHz or • P5024A/P5024B-400 Streamline USB/TBT Series VNA or • M9804A-400 PXI Multiport VNA	1
VNA Software	• S9x011B Enhanced time-domain analysis with TDR • S9x007B Automatic Fixture Removal (Optional) * Selection is based on the VNA platforms. x=6 for ENA, x=7 for Streamline VNA, x=5 for PXI, x=3 for PNA family	1
ECal	N4433D-010/0DC 4-Ports Electronic Calibration (ECal) Module	1
Test Fixture	USB Type-C official test fixture Fixtures for testing USB Type-C and USB 3.x legacy cable assemblies are available for purchase through LUXSHARE-ICT.	1

Note: The list includes key setup configurations. For full details, please refer to USB Type-C Test MOI.

Option 2: Automated solution using S94USBCB compliance software

The conventional test method using 4-ports VNA and test MOI (Option 1) could leads to long test time and lower productivity when it comes to USB4/USB3.x high speed signal test, TX/RX pairs crosstalk that required multiple port re-connections to complete one cable test. The new automated interconnects compliance test solution provides a fast and efficient way to test USB Type-C cables and connectors, reducing >90% test time of one USB Type-C cable compliance test.

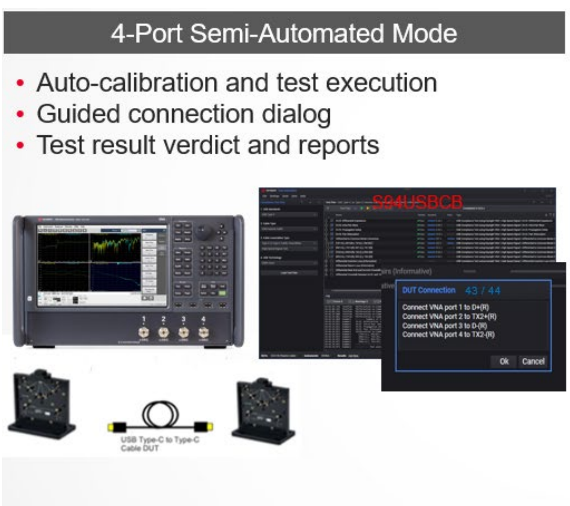
www.keysight.com/find/S94USBCB

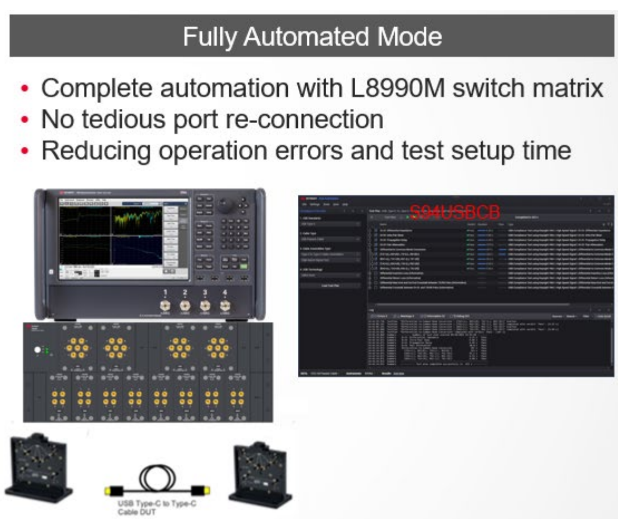
- Supports flexible test configuration across all Keysight VNA: E5080B VNA, PNA family, P502xA/B Streamline VNA series, and PXI-VNA series.
- Uses Keysight PathWave Test Automation platform for test sequencing and test automation.
- Automates all multiport measurements with L8990M 4-to-20 ports switch matrix system.
- Enables quick set up and calibration with the setup wizard
- Delivers accurate measurements with test fixture de-embedding and Automatic Fixture Removal (AFR)
- Integrates USB-IF compliance test tools (Get_iPar and IntePar) for full compliance test automation.
- Provides deeper insights of your measurements with comprehensive HTML test reports.

Try the software today!

Experience S94USBCB compliance software's powerful capabilities to improve your productivity and accelerate your USB Type-C compliance test workflow.

Download the 30-days free trial now!





Recommended configuration

Supports Mode	Item	Description	Quantity
4-Port Semi-Automated Mode	Network Analyzer	4-ports, min 20 GHz is required. • E5080B-4K0: 4-port test set, 9 kHz to 20 GHz or • P5024A/P5024B-400 Streamline USB/TBT Series VNA or • M9804A-400 PXI Multiport VNA	1
	VNA Software	S9x011B Enhanced time-domain analysis with TDR * Selection is based on the VNA platforms. x=6 for ENA, x=7 for Streamline VNA, x=5 for PXI, x=3 for PNA family	1
	High-Speed Digital Interconnects Compliance Tests Software Suite	S94USBCB - USB Type-C® Interconnects Compliance Test Software	1
		KS8400B - PathWave Test Automation	1
		KS8104B - HTML5 Result Listener Plugin	1
	ECal	N4433D-010/0DC 4-Ports Electronic Calibration (ECal) Module	1
	Test Fixture	USB Type-C official test fixture Fixtures for testing USB Type-C and USB 3.x legacy cable assemblies are available for purchase through LUXSHARE-ICT.	1
Fully Automated Mode	4-Port mode setup	Using same setup configurations as above 4-port semi-automated mode.	1
	Switch matrix	L8990M-0LZ: 4-to-20 ports switch matrix system, DC-26.5GHz. All required cables (24 test cables and 16 semi-rigid cables) are included.	1

Note: The list includes key setup configurations. For full details, please refer to S94USBCB product datasheet.

Web Resources

- www.keysight.com/find/S94USBCB
- www.keysight.com/find/hsd_interconnects_compliance
- Product Video - Automated Cable Test Solution
- Demo video – USB Type-C MOI and State File Solution
- www.keysight.com/find/ena-tdr_compliance
- www.keysight.com/find/ena
- 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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