RIGOL

USB 2.0 Compliance Test Solution

APPLICATION NOTE

May, 2022

RIGOL TECHNOLOGIES CO., LTD.

Preface

Copyright

Trademark Information

RIGOL® is the trademark of **RIGOL** TECHNOLOGIES CO., LTD.

Notices

- **RIGOL** products are covered by P.R.C. and foreign patents, issued and pending.
- **RIGOL** reserves the right to modify or change parts of or all the specifications and pricing policies at the company's sole decision.
- Information in this publication replaces all previously released materials.
- Information in this publication is subject to change without notice.
- **RIGOL** shall not be liable for either incidental or consequential losses in connection with the furnishing, use, or performance of this manual, as well as any information contained.
- Any part of this document is forbidden to be copied, photocopied, or rearranged without prior written approval of **RIGOL**.

Product Certification

RIGOL guarantees that this product conforms to the national and industrial standards in China as well as the ISO9001:2015 standard and the ISO14001:2015 standard. Other international standard conformance certifications are in progress.

Contact Us

If you have any problem or requirement when using our products or this manual, please contact **RIGOL**.

E-mail: service@rigol.com

Website: http://www. rigol.com

THIS APPLICATION NOTE WILL

- Provide a basic understanding of USB 2.0
- Describe the USB 2.0 signal quality test
- Provide information on the instruments required for the USB 2.0 signal quality test
- List criteria for selection of test equipment

It should take about 10 minutes to read the whole text.

Introduction

Universal Serial Bus (USB) is an interface technology that establishes specifications for connection and communication between computers and peripherals. Since its release in 1995, USB has been widely used in various peripherals, due to its speed, ease of use, and expandability. It is preferred by many consumers, gradually replacing the traditional serial and parallel ports.

However, this also brings some challenges for USB device manufacturers. To ensure the compliance of USB products, “the license agreement must be signed by a duly authorized representative of your company and sent to the USB Implementers Forum, Inc. in order to gain access to the logo artwork files and have the right to use the logos on products that pass USB-IF compliance testing”. **RIGOL** offers a comprehensive USB 2.0 signal quality test solution, enabling engineers involved in the design, test, and validation of USB devices to quickly perform USB 2.0 compliance tests with instruments, software, and test fixture provided by **RIGOL**.

This application note will introduce the test items and methods in USB 2.0 signal quality test and will include a discussion of the test equipment required for each test.

1. USB 2.0 Basics

USB 2.0 is a 4-wire serial bus: V_{BUS}, D+, D-, and GND. The D+ and D- pins are the differential pairs used for the USB 2.0 connectivity, serving as the prime carriers for communication between hosts, hubs, and devices.

USB 2.0 is backward compatible with USB 1.0/1.1. It superseded and incorporates the USB 1.1 specification which defined Low Speed (LS) and Full Speed (FS) data transfers; however, it also adds High Speed (HS) data transfers. The *Universal Serial Bus Specification Revision 2.0* describes the following three data transfer speeds, as is shown in Table 1.

Table 1 USB 2.0 Data Transfer Speeds

	Data Rate	Rise Time
Low Speed (LS)	1.5 Mbps	75 ns to 300 ns
Full Speed (FS)	12 Mbps	4 ns to 20 ns
High Speed (HS)	480 Mbps	About 500 ps

USB 2.0 electrical tests include signal quality, inrush current, as well as drop and droop tests. This application note mainly describes the signal quality test.

2. Signal Quality Test

Signal quality test is a complete set of basic electrical function tests. It is the key to ensure that a USB 2.0 device is compliant and will be awarded the USB 2.0 certified logo. The USB 2.0 signal quality test requires a digital oscilloscope, as well as compliant probes, cables, and test fixture. This will be discussed in more detail in a subsequent section.

The USB-IF provides clear test descriptions and compliance criteria in *USB 2.0 Specification*. It also authorizes the manual testing methods. However, manual test configuration, verification, results summary, and reporting can be a repetitive and time-consuming process, significantly reducing efficiency. **RIGOL** USB 2.0 compliance test software automates this process, allowing engineers to perform compliance tests accurately and efficiently. Figure 1 shows the USB 2.0 compliance test software running on the **RIGOL** DS70000 series oscilloscope.

Figure 1 **RIGOL** DS70000 USB 2.0 Compliance Test Software

The signal quality test includes:

- SYNC field
- End of Packet (EOP) width
- Signal rate
- Edge monotonicity test
- Rising time/rate
- Falling time/rate
- Paired JK jitter
- Paired KJ jitter
- Eye Diagram testing

2.1. SYNC Field

All packets begin with a synchronization (SYNC) field in USB protocol. The SYNC field is basically used to align incoming data with the local clock. In USB 2.0 buses, a simple clock recovery mechanism is used to realize synchronization through SYNC packets. The SYNC pattern used for high-speed transmission is required to be 15 KJ pairs followed by 2 K's to make up 32 bits of data. In short, the SYNC pattern for high-speed is required to be 32 bits.

2.2. End of Packet (EOP) Width

For the USB protocol, packets are terminated with an End-of-Packet (EOP). The width of EOP is defined in bit time. For SOF EOP, the width required ranges from 39.5 bits to 40.5 bits. For non-SOF EOP, the width ranges from 7.5 bits to 8.5 bits.

2.3. Signal Rate

The high-speed data rate (THSDRAT) is nominally 480.00 Mb/s, with a required bit rate accuracy of 500 ppm (480.00 Mb/s±0.05%). The full-speed data rate (TFDRAT) is nominally 12.000 Mb/s. The required data rate when transmitting is 12.000 Mb/s ±0.25% (2,500 ppm). The low-speed data rate (TLDRATE) is nominally 1.50 Mb/s. The required data rate when transmitting is 1.50 Mb/s ±1.5% (15,000 ppm).

2.4. Edge Monotonicity Test

It is required that high-speed data transitions should be monotonic over the minimum vertical openings in eye pattern templates. Hence, for USB 2.0 high-speed compliance, a developer needs to verify that the signal is monotonic. Monotonicity verifies that a transmitted signal smoothly increases or decreases in amplitude without deviation in the opposite direction. Figure 2 below illustrates the monotonic and non-monotonic signals.

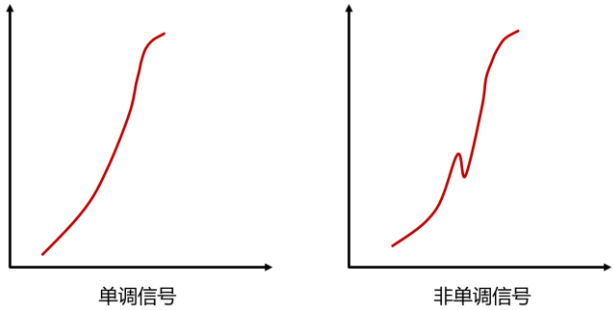


Figure 2 Illustration of monotonic and non-monotonic USB 2.0 high-speed signals

2.5. Rise/Fall Time

For low-speed and full-speed signals, the output rise time and fall times are measured between 10% and 90% of the signal (Figure 3). Rise and fall time requirements apply to differential transitions as well as to transitions between differential and single-ended signaling. For high-speed, the rise/fall time must be 500 ps or longer while the rise/fall rate must be less than or equal to 1600 V/μs.

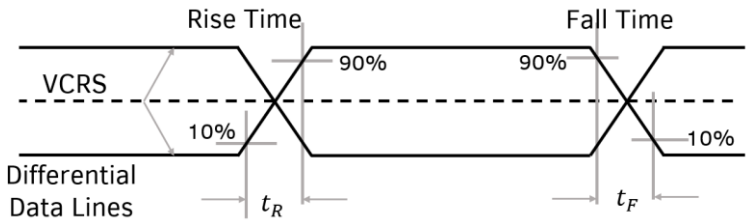


Figure 3 Rise and Fall Time

2.6. Jitter Test

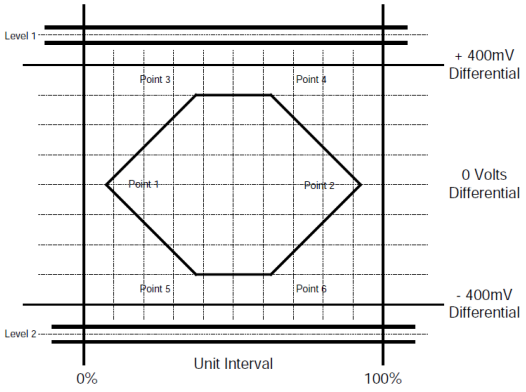
USB2.0 high-speed jitter test results are included in eye diagram testing results. The jitter types include consecutive jitter, paired JK jitter, and paired KJ jitter. The details are shown in the table below.

Table 2 USB 2.0 High-speed Jitter Measuring Items and Standards

USB 2.0 High-speed Jitter Measurement Items	Standard Range
Consecutive Jitter & RMS Jitter	-100 ps≤X≤100 ps
Paired JK Jitter & RMS Jitter	-100 ps≤X≤100 ps
Paired KJ Jitter & RMS Jitter	-100 ps≤X≤100 ps

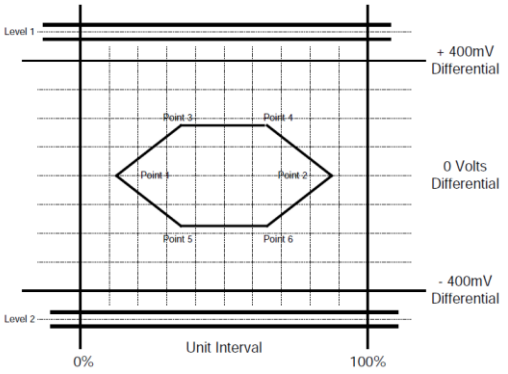
2.7. Eye Diagram Testing

In USB 2.0 compliance testing, an eye diagram is an important indicator of the quality of signals. The eye diagram results must conform to the eye pattern templates (as shown in figures below) defined by USB-IF. With built-in eye-diagram templates, **RIGOL** USB 2.0 test solution can directly provide test results by comparison of automatically plotted eye diagram with standard eye pattern templates.



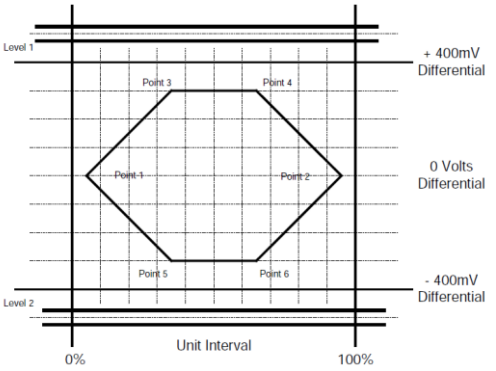
	Voltage Level (D+ - D-)	Time (% of Unit Interval)
Level 1	525 mV in UI following a transition, 475 mV in all others	N/A
Level 2	-525 mV in UI following a transition, -475 in all others	N/A
Point 1	0 V	7.5% UI
Point 2	0 V	92.5% UI
Point 3	300 mV	37.5% UI
Point 4	300 mV	62.5% UI
Point 5	-300 mV	37.5% UI
Point 6	-300 mV	62.5% UI

Figure 4 The transmit waveform requirements for a hub measured at TP2, and for a device (without a captive cable) measured at TP3



	Voltage Level (D+ - D-)	Time (% of Unit Interval)
Level 1	525 mV in UI following a transition, 475 mV in all others	N/A
Level 2	-525 mV in UI following a transition, -475 in all others	N/A
Point 1	0 V	12.5% UI
Point 2	0 V	87.5% UI
Point 3	175 mV	35% UI
Point 4	175 mV	65% UI
Point 5	-175 mV	35% UI
Point 6	-175 mV	65% UI

Figure 5 The transmit waveform requirements for a device (with a captive cable) measured at TP2



	Voltage Level (D+ - D-)	Time (% of Unit Interval)
Level 1	525 mV in UI following a transition, 475 mV in all others	N/A
Level 2	-525 mV in UI following a transition, -475 in all others	N/A
Point 1	0 V	5% UI
Point 2	0 V	95% UI
Point 3	300 mV	35% UI
Point 4	300 mV	65% UI
Point 5	-300 mV	35% UI
Point 6	-300 mV	65% UI

Figure 6 The transmit waveform requirements for a hub transceiver measured at TP1 and for a device transceiver measured at TP4

2.8. USB 2.0 Signal Quality Test Results

Figure 7 shows the USB 2.0 compliance test report on DS70000. The report displays the measuring items and their maximum/minimum limits, measured values, and pass/fail results. As the tested USB 2.0 flash drive is intact, it satisfies the criteria for all items. Hence, all results display “Passes” in the last column; otherwise, “Failure” is displayed.

USB2.0 Far End Test Results (Ref: USB Specification Revision 2.0)

Test Information	Report Time: 2021-11-04 11:04:34 1.0.0.0

Measure

Item	Measured Value	Minimum	Maximum	Result
SYNC	32 bits	32 bits	32 bits	Passes
EOP Width	7.749 bits	7.5 bits	8.5 bits	Passes
Signal Rate	480.134 Mb/s	479.76 Mb/s	480.24 Mb/s	Passes
Edge Monotonicity	0 mV	0 mV	50 mV	Passes
Rise Edge Time	726.14 ps	500 ps	NA	Passes
Fall Edge Time	736.46 ps	500 ps	NA	Passes
Rise Edge Rate	1029.88 V/us	NA	1600 V/us	Passes
Fall Edge Rate	1015.45 V/us	NA	1600 V/us	Passes
Consecutive Jitter	Range: -61 ps to 48 ps; RMS jitter: 29.09 ps	-100 ps	100 ps	Passes
Paired JK Jitter	Range: -35 ps to 36 ps; RMS jitter: 16.98 ps	-100 ps	100 ps	Passes
Paired KJ Jitter	Range: -37 ps to 36 ps; RMS jitter: 21.86 ps	-100 ps	100 ps	Passes
Signal Eye	0 data points violate eye	0	0	Passes

Figure 7 DS70000 USB 2.0 Compliance Test Report

The USB 2.0 compliance analysis software analyzes the quality of the standard signal from the interface (test packets are generated from the XHCI HSETT recommended by USB-IF). Figure 8 shows the captured test packet; figure 9 shows the calculated eye diagram with template.

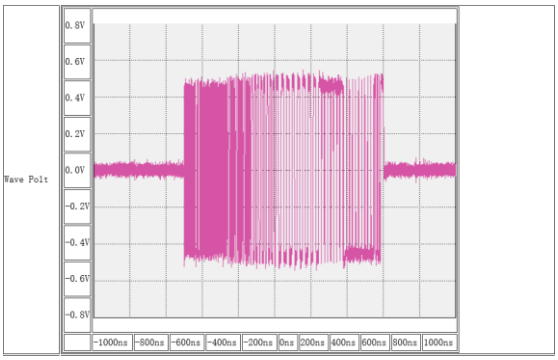


Figure 8 Acquired Waveform for Analysis Results

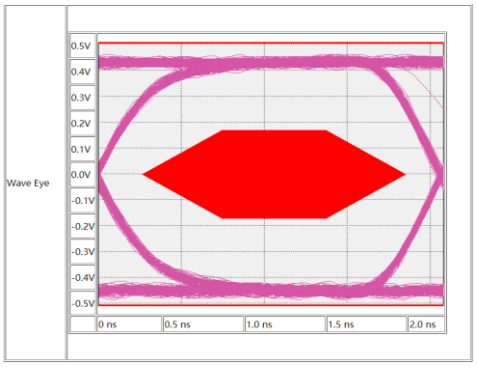


Figure 9 Eye Diagram Template Analysis

Just like the eye pattern templates defined in *USB 2.0 Specification*, the bigger the opening of the “eye,” the better. An eye diagram that looks “stressed” indicates poor signal quality.

3. Instrumentation Requirements for USB 2.0 Signal Quality Test

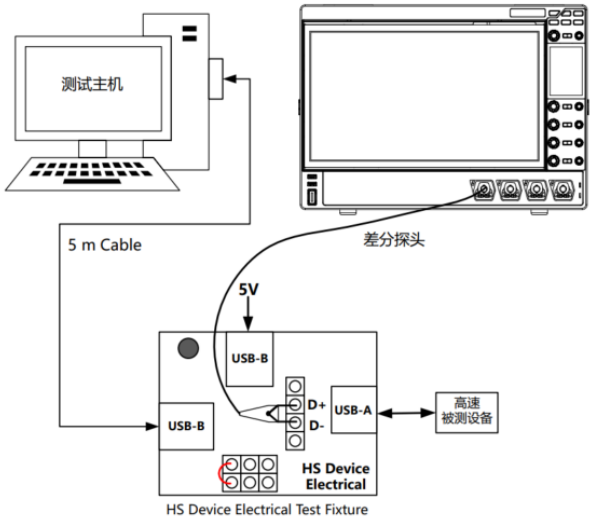


Figure 10 Connection Diagram of the High-speed Device Signal Quality Test

Recommended test equipment for USB 2.0 high-speed measurements:

- **RIGOL** tool set containing active differential probe:

Table 3 Tool Set Containing Active Differential Probe

Qty	Item	Description/Model
1	Oscilloscope	DS70304/DS70504
1	USB 2.0 compliance test software	DS70000-USBC
1	Differential probe	PVA7250/PVA8000 Series Active Probe
1	Test fixture	Standard test fixture specified by USB-IF or **RIGOL** test fixture in accordance with the *USB 2.0 Specification*
1	Software tool from USB-IF to generate test packets	USBHSETT (available at usb.org)
1	5 V power cable	USB A Male to B Male cable (Cable_USB)

- **RIGOL** tool set containing coaxial cables:

Table 4 Tool Set Containing Coaxial Cables

Qty	Item	Description/Model
1	Oscilloscope	DS70304/DS70504
1	USB 2.0 compliance test software	DS70000-USBC
1	Test fixture	Standard test fixture specified by USB-IF or **RIGOL** test fixture in accordance with the *USB 2.0 Specification*
2	SMA-BNC cable	SMA-BNC testing cable
1	5 V power cable	USB A Male to B Male cable (Cable_USB)

4. Selecting Tools for USB 2.0 Signal Quality Testing

USB 2.0 signal is a differential signal with up to 480 Mbps signaling bit rate and 240 MHz frequency. Tr is approximately 1/10 of the period, that is, 417 ps. If only the signal rate is considered to observe the waveform's quintuple harmonics, the oscilloscope bandwidth is required to be 2.5 times the signal rate, that is, 1.2 GHz (480M*2.5) to capture the USB 2.0 signals. However, considering the USB-IF requirements, for signals with Tr=417 ps which is within 500 ps, the bandwidth required for the oscilloscope to obtain 10% measurement accuracy is 1/Tr=2.4 GHz.

According to USB-IF, the testing requires an oscilloscope with a bandwidth above 2 GHz and a sampling rate of 5GS/s. Nonetheless, this application note demonstrates the USB 2.0 compliance test using **RIGOL** DS70000 series real-time sampling digital oscilloscope with up to 5 GHz bandwidth and 20 GSa/s sample rate to obtain higher measurement accuracy.

Figure 11 DS70000 Series Digital Oscilloscope

Along with the oscilloscope, testing requires high-speed active differential probe, active single-ended probe, and USB 2.0 signal quality test fixture. In this case, **RIGOL** provides compliant probes including high-speed active differential probes (PVA7000/PVA8000 series) and high-speed single-ended active probe (RP7000S series).

Figure 12 PVA8000 Series Active Differential Probe

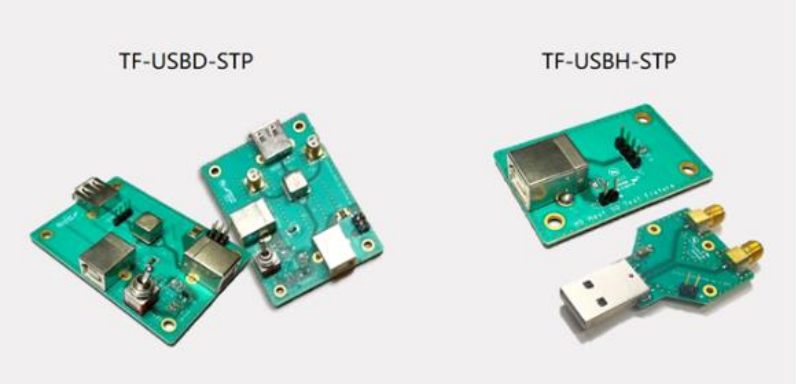


Figure 13 USB Compliance Test Fixture

In addition, testing also requires a test fixture approved by USB-IF. **RIGOL** can provide test fixtures including device test fixtures (TF-USBD-STP) and host test fixtures (TF-USBH-STP).

5. Conclusion

USB 2.0 interface has become the perfect choice for peripheral device manufacturers, thanks to its benefits — higher transfer rate, hot-pluggable ability, capability to connect multiple devices, and ease-of-use that users have come to demand. However, this improved standard and compatibility also present new design challenges that device designers must resolve.

RIGOL offers a comprehensive tool set — digital oscilloscope, professional test fixture and probe, and fully automatic compliance test software — to enable USB 2.0 device designers to perform quick and accurate electrical compliance testing and analysis.

RIGOL is committed to providing engineers with comprehensive test solutions. For details, please visit www.RIGOL.com

HEADQUARTER

RIGOL TECHNOLOGIES CO., LTD.
No.8 Keling Road, New District, Suzhou,
JiangSu, P.R.China
Tel: +86-400620002
Email: info@rigol.com

EUROPE

RIGOL TECHNOLOGIES EU GmbH
Carl-Benz-Str.11
82205 Gilching
Germany
Tel: +49(0)8105-27292-0
Email: info-europe@rigol.com

NORTH AMERICA

RIGOL TECHNOLOGIES, USA INC.
10220 SW Nimbus Ave.
Suite K-7
Portland, OR 97223
Tel: +1-877-4-**RIGOL**-1
Fax: +1-877-4-**RIGOL**-1
Email: info@rigol.com

JAPAN

RIGOL JAPAN CO., LTD.
501, LATORRETTA, 2-37-1,
Numabukuro,
Nakano-Ku, Tokyo, Japan
Tel: +81-3-6262-8932
Fax: +81-3-6262-8933
Email: info-japan@rigol.com