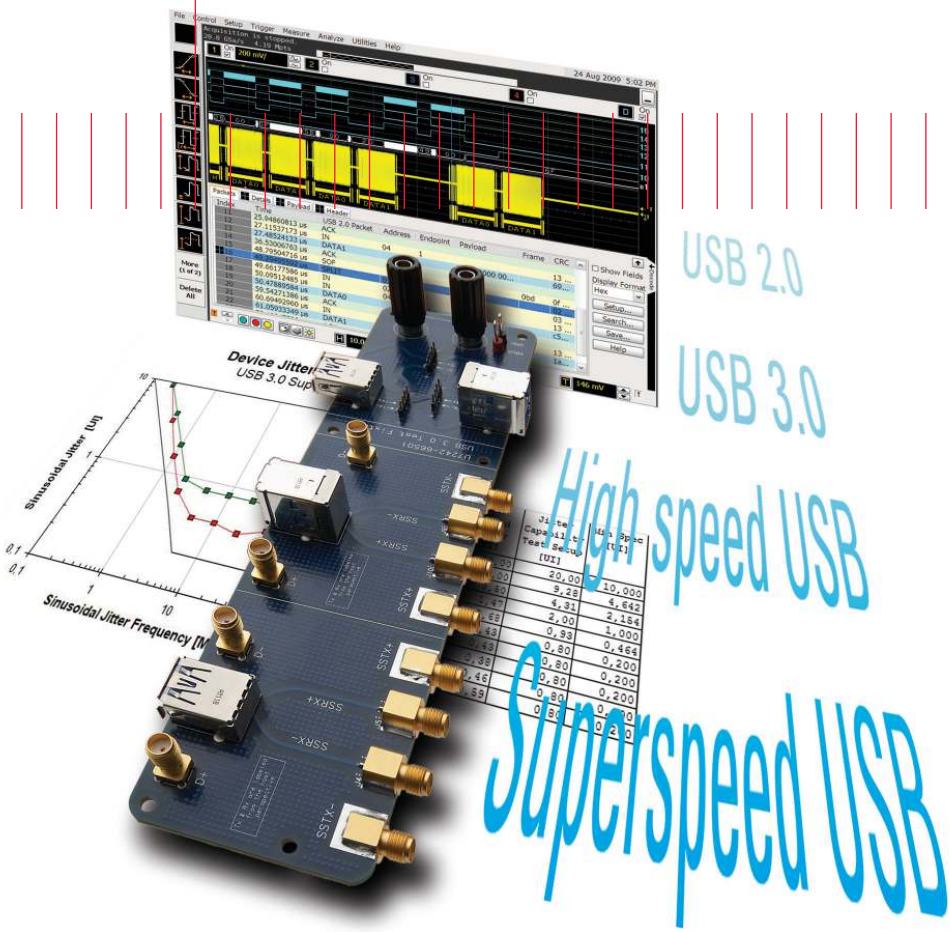
Keysight Technologies
USB Design and Test – A Better Way

Brochure



KEYSIGHT TECHNOLOGIES

Testing for Interoperability

The Universal Serial Bus (USB) was first introduced in 1995. USB delivered a new way to connect personal computers and devices and allows users to easily connect many different types of devices and peripherals. As a result USB has essentially replaced aging serial and parallel ports as the connection of choice for device manufacturers and end users.

One of the biggest factors in the incredible success of USB has been the successful interoperability of USB devices and hosts. Interoperable products are an indirect result of the compliance testing program developed and maintained by the USB-Implementers Forum (USB-IF).

The USB-IF publishes compliance test specifications and has developed a comprehensive set of compliance tests that are used to verify quality and conformance of USB designs.

If you can demonstrate that your products meet these specifications then your customers can be confident that your products will work with theirs.

Proving that your products comply with the USB-IF specification requires a test methodology that meets the definitions contained within the CTS (Compliance Test Specification) published by the USB-IF.

Successful compliance testing provides many benefits. Firstly, logo certification - a product will only gain accreditation to use the official USB logos when proof is given that it meets the Compliance Test Specification.

Secondly, interoperability - as a product designer you cannot predict nor control the user's environment. Products must be submitted to a robust testing methodology in order to minimize the potential for interoperability problems when connected to a real device in the real world.

Finally, customer confidence - your customers need to be assured that the products you deliver will work in their OEM environments. By testing to a proven method with approved test solutions you give your customers the confidence that your products conform to the CTS and will work effectively in their designs.

Keysight Technologies, Inc. is the world's leading Test and Measurement Company. Keysight's USB test solutions are fully approved by the USB-IF and are used in compliance workshops and by test labs worldwide.

When you test your USB designs with Keysight's test solutions you have the confidence that when your products pass they meet the requirements of the USB-IF Compliance Test Specification.

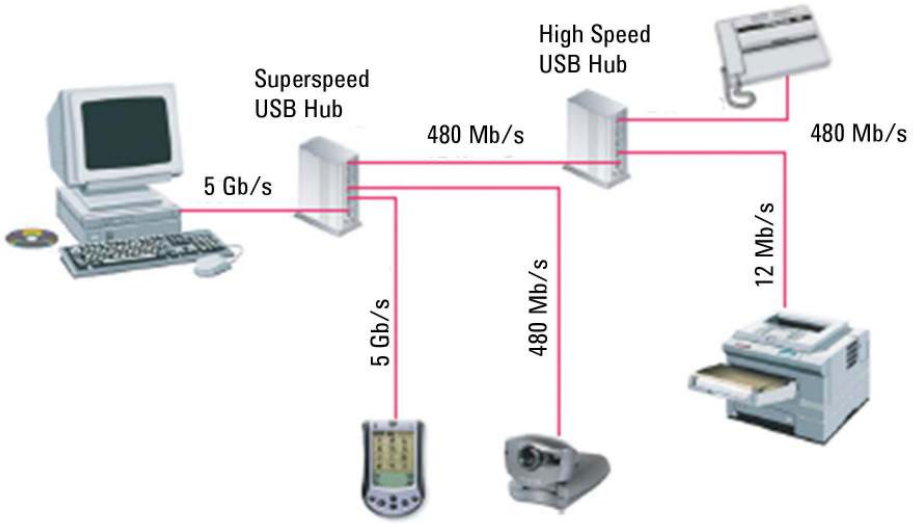


Figure 1. USB 3.0 systems can manage all four data rates concurrently

Keysight gets involved, you benefit

Keysight's solutions for digital applications are driven and supported by Keysight experts that are involved in the various international standard committees. We call it the Keysight Digital Test Standards Program. Our experts are active in the Joint Electronic Device Engineering Council (JEDEC), PCI Special Interest Group (PCI-SIG®), Video Electronics Standards Association (VESA), Serial ATA International Organization (SATA-IO), USB-Implementers Forum (USB-IF), Mobile Industry Processor Interface (MIPI) Alliance, Ethernet standards (IEEE 802.3), Optical Internetworking Forum (OIF), and many others. Our involvement in these standards groups and their related workshops, plugfests, and seminars enables Keysight to bring the right solutions to the market when you need them.

The USB Platform

Since the introduction of USB, the USB-IF has continued to launch new variants of the interface standard.

In 2000, the USB-IF announced USB 2.0 to provide increased data throughput for higher-bandwidth devices such as video-conferencing cameras and high-resolution printers.

USB 2.0 provided the choice of three data rates, Low speed at 1.5 Mb/s, Full speed at 12 Mb/s and High speed at 480 Mb/s.

A further development has seen the introduction of Wireless USB, allowing users to wirelessly interconnect up to 127 devices. Wireless USB delivers a bandwidth of up to 480 Mb/s at 3 meters and 110 MB/s at 10 meter

Now a further enhancement to the USB platform has been announced with the release of SuperSpeed USB 3.0. USB 3.0 is backward compatible with earlier versions and has been designed to address the high bandwidth transport requirements of rich media and large digital files. USB 3.0 provides a 10-fold increase in the data transfer rates compared with USB 2.0 with a data rate specified up to 5 Gb/s and data throughput greater than 200 MB/s.

The architecture of USB is such is that all of these data rates can co-exist at the same time within a configuration, all controlled by a common PC host.

This gives the flexibility to mix and match peripherals with different needs in terms of speed and throughput.

The family of USB specifications, USB 2.0, wireless USB and now USB 3.0, meet the needs of different applications and it is anticipated that all will co-exist in the market. Designers will choose the specification to meet the particular needs of their product. Whatever choice is made a robust test methodology is required to ensure that the end product is compliant to the relevant standards.

For designers of USB devices and systems the successful completion of the compliance test regime is essential to ensure conformance to the standards and interoperability.

Each variant of USB has its own compliance test specification. A number of the tests are common between variants, however, as the data rates increase then the requirement for a more thorough testing of high-speed effects increase. RF effects need to be considered when validating the high-speed modes of USB 2.0 and for USB 3.0.

Keysight Technologies offers a portfolio of solutions for testing USB, addressing all of the current variants. The company participates actively in the USB Implementers Forum (USB-IF) allowing it to influence and respond rapidly to changes in the test specifications.

Keysight's USB-IF approved test solutions are used in compliance workshops and by test labs all over the world.

Keysight Technologies' comprehensive portfolio of test solutions addresses the compliance testing needs of all variants of USB. With Keysight's oscilloscopes, BERTs, network and logic analyzers together with a range of USB specific test applications and fixtures you can quickly and accurately test your USB design to ensure compliance.

When you select Keysight as your test partner you can be assured that your products will be tested to the latest standards and on the same equipment as used by your test lab. The result: you can speed your compliance, reduce your design iterations and shorten your time to market.

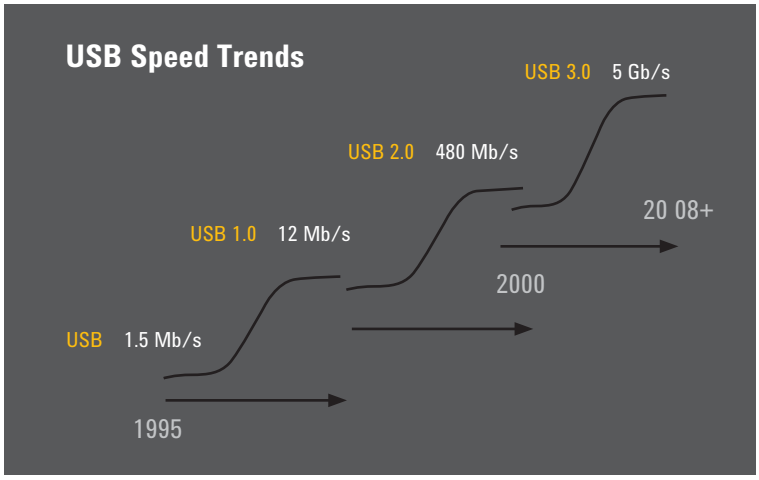


Figure 2. Evolution of USB

USB 2.0 Test Solutions

The USB 2.0 cabling system comprises four wires, two signal (D+ and D-), power (Vbus) and ground. D+ and D- are configured as a differential signal pair used in NRZI half-duplex mode and serve as the primary information carrier between the host, hubs and peripherals. Devices may be either bus powered with a limit of 500mA current drain or self powered using a in-built power supply.

USB 2.0 specifies three different data rates, low speed at 1.5 Mb/s, full speed at 12 Mb/s and high speed at 480 Mb/s. All three data rates can exist concurrently in a network of USB devices. Any of up to seven peripheral devices on the bus must be able to interface with its hub and the hubs must be able to interface with the host.

The flexibility inherent in USB is a direct result of the stringent specifications, regulations and compliance testing mandated by the USB-IF. To ensure your products comply with the USB 2.0 specifications require extensive testing. To prove electrical compliance requires that signal integrity, current and voltage parametric, and data integrity testing is undertaken. High speed USB 2.0 in addition requires that high speed signal quality, receiver sensitivity, CHIRP timing (high speed handshake) and packet parameters are tested.

Signal Quality Tests

The basic USB 2.0 electrical test suite includes signal quality, in-rush current and voltage droop/drop tests. For signal quality testing an oscilloscope is used to observe the signals being transmitted and received. The oscilloscope allows a range of parameters to be measured including signal eye, end of packet width, signaling rate, rise/fall times, cross-over voltage and jitter.

Keysight Infiniium 9000 Series oscilloscopes together with Keysight probes and test fixtures are critical for reproducing the USB-IF specified tests. The Keysight USB Compliance Test Software makes USB signal integrity compliance testing as simple as making an automatic measurement. By integrating a run-time version of MATLAB within the oscilloscope for use with the USB-IF test scripts the USB Compliance Test Software provides you with a one-box solution to speed your signal quality testing as well as provide you with confidence your results will be consistent to those obtained at certification events or USB-IF approved test labs.

Data Integrity Test

Determining the cause of a data error or a performance problem in a USB network can be challenging. Logic and protocol analysis allows you to see data traffic, make critical timing measurements, and verify protocols, making it the ideal tool for detecting and debugging higher-level data integrity problems.

The Keysight Infiniium 9000 Series Mixed Signal Oscilloscopes include integrated built-in logic and protocol analysis capabilities. The in-scope protocol viewer and debug application software with protocol triggering and USB serial decode allows you to extend your debug and testing capabilities without the use of additional test equipment.

Keysight's Infiniium 9000 Series oscilloscopes have the only scope based protocol viewer and the widest range of debug and compliance applications.

High Speed Tests

High speed USB 2.0 requires that high speed signal quality, receiver sensitivity, CHIRP timing and packet parameters are tested. Since the connection scheme for USB 2.0 uses a single pair of wires for both transmit and receive paths high speed signal quality testing has to be sequenced between sending a stimulus and then measuring the response.

Keysight's USB 2.0 Receiver Test Library utilizes the Keysight 81134A pattern generator and an Infiniium oscilloscope for extensive receiver testing. The device under test is put into the SEO_NAK mode and the pattern generator is used to apply an amplitude and bit pattern controlled stimulus to test the sensitivity level of the receiver. The Infiniium Oscilloscope test software automatically controls the signal source to easily and quickly sequence through the required tests. Additionally, Keysight provides the industry's only automated jitter tolerance test solution for USB 2.0 using the Keysight N5990A software platform. The receiver sensitivity and squelch thresholds are then measured using the oscilloscope.

Together with the USB Compliance Test Software this ensures that your products are tested to be fully compliant to the USB 2.0 specification requirements.

The Keysight USB Compliance Test Software makes USB signal integrity compliance testing as simple as making an automatic measurement.

USB 2.0 Key Advantages

Most Efficient and Accurate

Full automation and integrated MATLAB scripts save time and eliminate errors. Other vendor's USB solutions pre-compliance testing in a lab environment involves capturing data with an oscilloscope, transferring it to a PC and post-processing it with a software program. Keysight has simplified the process by installing a run-time version of MATLAB software in the scope and integrating the USB-IF USB test option into the Infiniium oscilloscope's menu structure. Once the test is executed, the test results appear on the Infiniium display in an HTML-formatted window. Each test also automatically saves the PNG, HTML, and TSV files required by the USB-IF – other vendor's solutions do not and require manually creating the necessary files. The HTML reports that Keysight automatically create are complete with test configuration, all measurements made, pass/fail status, margin analysis, waveforms and the USB-IF approved MATLAB outputs.

Additionally, with full automation, the oscilloscope is set up automatically for each test to ensure correct measurement configuration. For example, Keysight's receiver tests communicate between the pattern generator and oscilloscope to automatically load the correct test patterns into the pattern generator, adjust voltages and automatically trigger and measure NAK responses to find pass/fail points for each receiver test as described by USB-IF.

Other vendor solutions require the user to manually load patterns in the pattern generator, manually adjust the differential signal voltages to find NAK responses, and manually mark and measure pass/fail voltage levels. This manual process is time consuming and prone to errors.

Protocol Triggering and Decode

Keysight's 9000 series oscilloscope is the only to offer protocol triggering and decode capabilities.

Trigger on and quickly view USB packets, payload, header and detail information. Powerful time-correlated views of waveform and symbol, to the bit level, make it easy to isolate communication faults to logic or analog sources. Efficiently debug your HSIC, UTMI, ULI or other MAC/PHY interface quickly to track down bit error locations. Quickly move between physical and protocol layer information using the time-correlated tracking marker. Display protocol content using waveform symbols and the industry's first multi-tab protocol viewer. The packets tab shows a high level view of the packet over time.

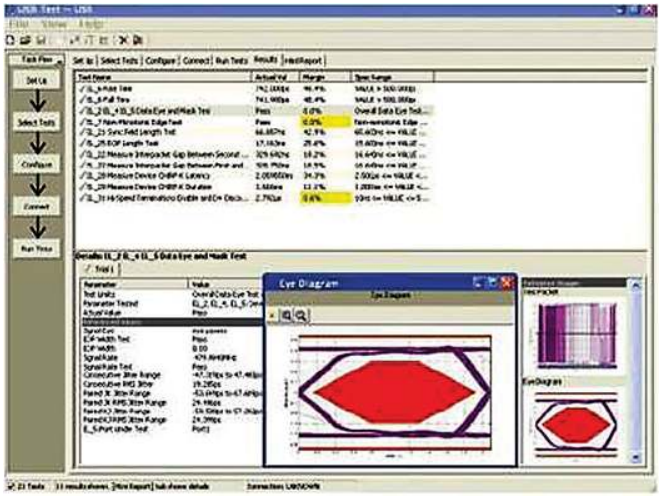


Figure 3. Matlab output from application

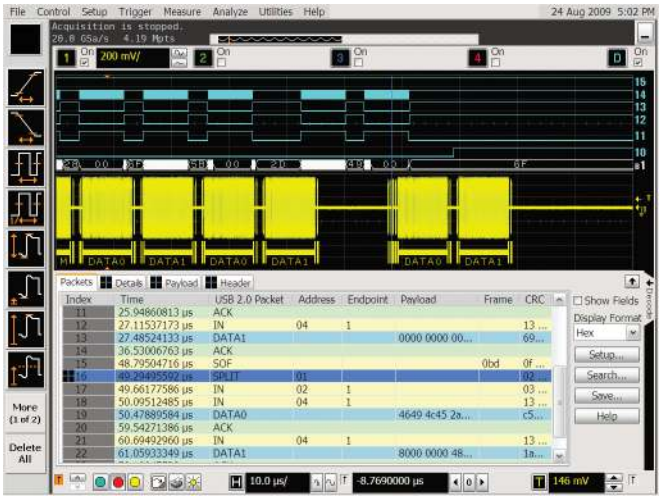
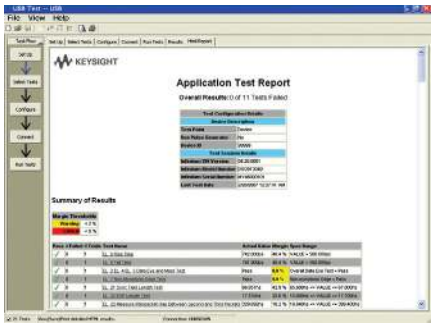


Figure 4. Series 9000 protocol output

Keysight USB 2.0 Test Portfolio

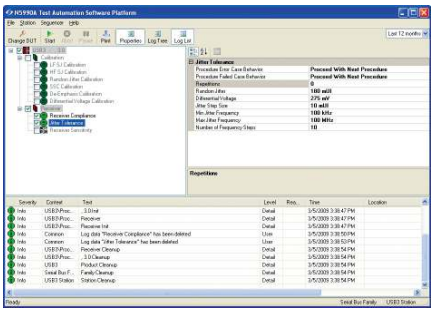


N5416A USB Compliance Test Software

The N5416A compliance test software for Infiniium oscilloscopes gives you a fast and reliable way to verify USB electrical specification compliance for USB 2.0 hosts, hubs and devices. The software executes the official USB-IF MATLAB scripts with MATLAB's runtime engine embedded in the oscilloscope for guaranteed correlation with official USB-IF test requirements. The software also automates the receiver testing providing the fastest receiver testing and compliance verification tools available.

Infiniium 9000 Series Oscilloscopes

The Infiniium 9000 Series mixed signal oscilloscopes provide analog bandwidths of up to 4GHz and built-in logic and protocol analysis. In addition to impressive analog specifications the Infiniium 9000 includes fast, integrated 2GSa/s digital channels and an in-scope protocol viewer for USB.



USB 2.0 Receiver Test Library

The Keysight USB 2.0 receiver test library N5990A option 102 complements the N5416A compliance test suite with additional receiver tests including intra-pair skew, jitter tolerance, carrier skew, squelch test and differential sensitivity tests. For receiver testing the N5990 option 102 is used in conjunction with a Keysight 81134A pulse pattern generator and an Infiniium oscilloscope. Option 202 is the interface to N5416A.

Low, Full and High Speed Test Fixtures

Keysight offers a range of test fixtures that meet the requirements of the USB-IF compliance test specification. For low and full speed compliance testing an E2646A SQuIDD (Signal Quality inrush Droop Drop) test fixture is required. High speed USB compliance testing requires the E2649A/B fixtures. For On-The-Go (OTG) USB testing Keysight offers the industry's only OTG Electrical Test (OET) fixture.

USB 3.0 Test Solutions

USB 3.0 has been introduced to address some of the performance bottlenecks of USB 2.0. High speed USB 2.0 provides a data rate of 480 Mbps. However, the real data throughout is typically much less with I/O performance limitations typically allowing less than 35 MB/s.

When downloading larger files higher throughput is required to allow manageable transfer times. USB 3.0 provides up to 5 Gb/s data rate and greater than 200 MB/s data throughput.

To achieve this higher level of performance USB 3.0 adds 4 additional wires to the interconnection. The cabling system comprises 8 wires in total, 4 of these conform to USB 2.0 and are used to ensure backward compatibility. The additional wires are configured as two additional pairs that are dedicated to USB 3.0 communications. These operate in Full Simplex mode with one pair for transmit and one for receive.

The 10-fold increase in data rate of USB 3.0 poses new challenges in testing the transmitter, receiver and cabling system.

Keysight's well established position as the leader in RF and Microwave design and test allows it to apply its expertise to the high speed testing needs of the USB 3.0 standard.

	Song / Pic	256 Flash	USB Flash	SD-Movie	USB Flash	HD-Movie
	4 MB	256 MB	1 GB	6 GB	16 GB	25 GB
USB 1.0	5.3 sec	5.7 min	22 min	2.2 hr	5.9 hr	9.3 hr
USB 2.0	0.1 sec	8.5 sec	33 sec	3.3 min	8.9 min	13.9 min
USB 3.0	0.01 sec	0.8 sec	3.3 sec	20 sec	53.3 sec	70 sec

Figure 5. Table of performance for different file types

Transmitter Tests

For USB 3.0 transmitter testing compliance must be measured at the end of a 'compliance channel' with SMA termination for the transmitter signals using a phase matched SMA cable.

Keysight's USB 3.0 test fixture provides a high performance USB 3.0 signal breakout with support for both transmitter and receiver testing with the SMA terminations.

When testing the transmit path a high-speed oscilloscope must be used to measure the transmitted waveform using compliance patterns. This will allow eye diagram analysis and the measurement of signal amplitudes, jitter, average data rate and rise/fall times.

Keysight's 90000 series of oscilloscopes provide up to 13 GHz of bandwidth. Together with the U7243A USB 3.0 Transmitter Compliance Test Application the oscilloscope can be used to perform transmitter compliance and validation testing as defined by the USB 3.0 specification.

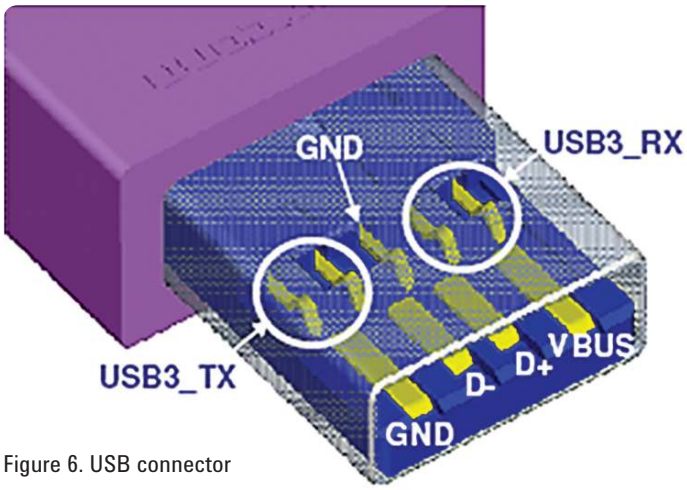


Figure 6. USB connector

Keysight's Infiniium 90000 Series oscilloscopes provide the lowest noise floor, jitter noise floor, and trigger jitter in the industry.

Receiver Tests

USB 3.0 specifies an error counter within the device that can internally check the error performance of the receiver. The specification also provides test modes that include the ability to loop back the received data over the device's transmitter.

Testing receiver sensitivity requires a controlled stimulus or pattern generator, which can provide a calibrated jitter input to the receiver under test. Measuring using the integrated error counter requires the use of an oscilloscope or BERT to read and decode the resulting value. Without an internal error counter testing in asynchronous loopback mode requires a BERT or protocol analyzer to evaluate the resulting bit stream for errors.

The error counter approach is limited to the compliance pattern that can be recognised by the internal device. Although this is adequate for simple pass/fail testing it does not allow for debugging and characterization.

Generally receiver stress testing is used to characterize the performance of the USB device under varying conditions of amplitude and jitter. It requires a pattern generator that can apply these different conditions including the ability to generate true random jitter for the target BER.

Keysight's portfolio of test solutions addresses all of these issues. For USB 3.0 the Keysight's N4903B J-BERT can generate the patterns necessary to stimulate the device, including the ability to stress the device for jitter tolerance testing. The captured result can be decoded using an oscilloscope together with the Keysight N5990A test automation software platform. Alternatively Keysight's BERT together with SuperSpeed protocol analysis solutions from Ellisys (www.ellisys.com) can be used in loopback mode to characterize the resulting performance of the device. The Ellisys EX280 is integrated in the N5990A Test Automation Software; therefore, both the JBERT and the EX280 are fully automated.

Channel Tests

Due to the increased bandwidth and longer channel lengths of USB 3.0 more testing is required for cables, connectors and channel validation.

TDR/TDT measurements are essential to ensure that designs meet the differential impedance and skew targets. VNA measurements are necessary to allow accurate verification of return loss, insertion loss and near/far end crosstalk requirements.

Keysight's test portfolio allows you to test all aspects of USB 3.0, the transmitter, the receiver, the channel and the cabling system.

Keysight's USB compliance portfolio meets the compliance test coverage requirements defined by the USB-IF. This means that when using Keysight's test solutions you can be assured your products are tested to the latest standards.

Keysight's J-BERT N4903B offers the only complete jitter tolerance testing for receivers up to 12.5 Gb/s. The N4903B characterizes the jitter tolerance and margins of receivers by providing half-rate clocks with variable duty-cycle distortion to emulate effects of non-ideal clocking. This allows the most accurate charactrization, enabling more robust designs.

USB 3.0 Key Advantages

Automation Rx testing

Jitter tolerance curves are key to understanding the real jitter performance of a receiver. The N5990A Test Automation Platform offers not only automated receiver compliance testing, but also automated receiver characterization including jitter tolerance (see Figure7). Realistic conditions are emulated and certain properties of the signal deliberately stress specific building blocks of the DUT. Unlike other time consuming solutions that create the files in software to load waveforms for each individual jitter test point, the N5990A sweeps using the proper stimulus signal including calibrated jitter; thus, reducing measurement time to a minimum. Automated calibration capabilities are critical to ensuring that normal variations in instrument jitter characteristics and interconnect tolerances are compensated prior to testing.

Test Fixture

The U7242A USB 3.0 test fixture will help simplify the USB 3.0 measureme process by providing access to the transmitter and receiver measuremen points required for USB 3.0 complianc testing. It has been designed for direct SMA connections for easy and accurate measurements with direct connections to the oscilloscope and J-Bert SMA connections. It also includes probing connections for InfiniiMax active differential probes for the characterization and testing of active bus signalling of USB 3.0 and USB 2.0 traffic.

Investment protection

Keysight's USB solutions offer investment protection due to signal generation and analysis capability for the bus standards USB, PCI Express®, SATA and DisplayPort testing. The same transmitter and receiver hardware can be used for al these bus standards. Additionally, th 90000 series oscilloscope offers the industry's only upgradeable BW for real time scopes, upgradable memor and the industry's only application server licenses.

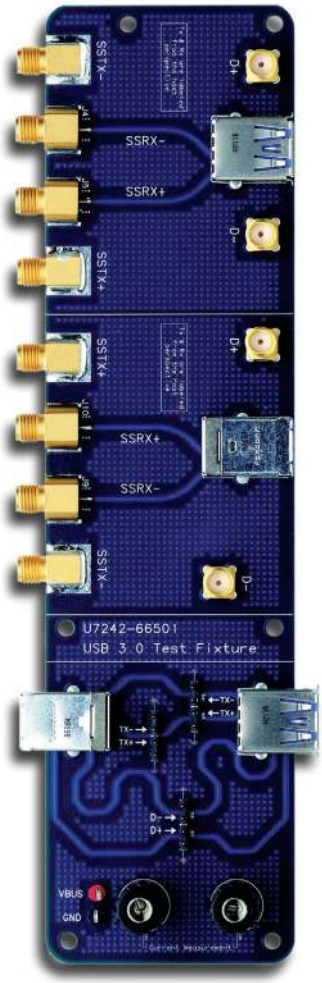
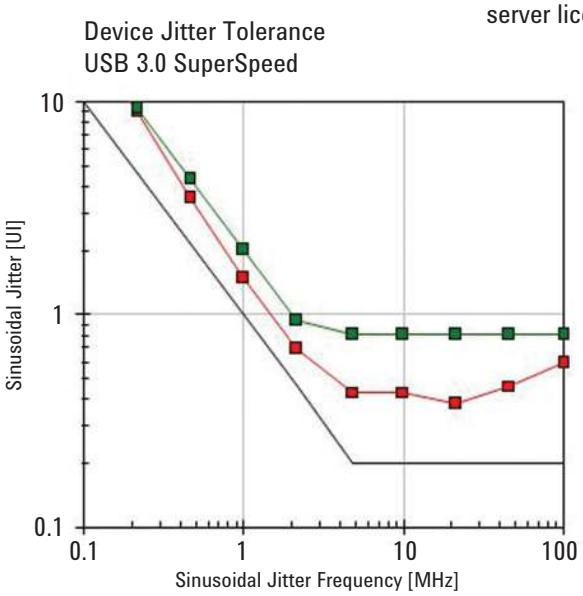


Figure 8. USB 3.0 fixture



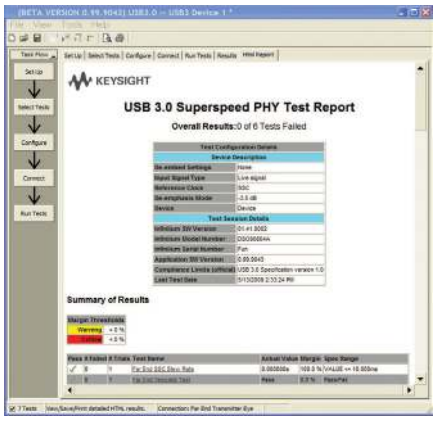
Max Passed Jitter
Jitter Capability Test Setup
Min Spec

Result	Sinusoidal Jitter Frequency [MHz]	Max Passed Jitter [UI]	Jitter Capability Test Setup [UI]	Min Spec [UI]
pass	0,100	20,00	20,00	10,000
pass	0,215	9,00	9,28	4,642
pass	0,464	3,50	4,31	2,154
pass	1,000	1,47	2,00	1,000
pass	2,154	0,68	0,93	0,464
pass	4,900	0,43	0,80	0,200
pass	10,000	0,43	0,80	0,200
pass	21,544	0,38	0,80	0,200
pass	46,416	0,46	0,80	0,200
pass	100,000	0,59	0,80	0,200

Figure 7. Jitter Tolerance

Keysight USB 3.0 Test Portfolio

Physical Layer: Interconnect Design	Physical Layer: Active Signal Validation	Protocol Validation	Functional Test



USB 3.0 Transmitter Compliance Test Application

U7243A USB 3.0 Superspeed Electrical Performance Validation and Compliance Software for the Infiniium Oscilloscoopes

The U7243A USB 3.0 electrical test software utilizes the prescribed test methods and algorithms as defined in the USB 3.0 rev 1.0 specification and draft test specification.

By incorporating the USB-IF SigTest utility the U7243A USB 3.0 electrical test software will provide you with consistent lab compliance test results with those generated at USB-IF workshops or test labs that use the standalone USB-IF SigTest tool for transmitter compliance verification.

DSO/DSA91304A 13-GHz Oscilloscope

The Keysight 90000 Series Infiniium oscilloscopes deliver the highest performance real-time measurement system available. The Infiniium 90000 Series offers the industry's lowest noise floor, jitter noise floor, and trigger jitter, making it the ideal tool for signal integrity and jitter measurements. Models are available from 2.5 GHz to 13 GHz, and can be upgraded in bandwidth for future needs.

USB 3.0 Test Fixtures

Keysight U7242A USB 3.0 Electrical Test Fixture:

The U7242A USB 3.0 Test Fixture will help simplify the USB 3.0 measurement process by providing access to the transmitter and receiver measurement points required for USB 3.0 compliance testing.

- Provides test point access for transmitter measurements
- Single ended measurements as required by the USB 3.0 specification for transmitter and receiver validation and compliance testing
- Differential measurements using active probes allow probing of active bus transactions for debug and verification testing
- USB 3.0 power probing features for easy measurement of transient and steady state power states

J-BERT N4903B High Performance Serial BERT

The recommended Keysight USB 3.0 receiver test solution is based on the J-BERT N4903B.

J-BERT B integrates a high quality, precision data generator and pre-calibrated jitter sources for reliable and repeatable test results. By design J-BERT B test results will be consistent even across multiple instances of J-BERT B.

Its random jitter capabilities comply with the standard's target bit error ratio requirements and is based on a true random noise source (no bounded periodic random jitter)

J-BERT B provides controls to vary signal stress conditions on the fly and during test execution. For example signal amplitude or jitter stress levels can be modified in real-time while the test is running.

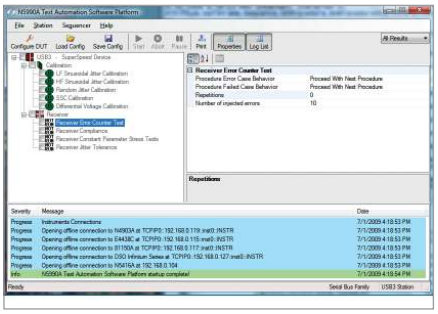
The J-BERT B pattern sequencer and memory based pattern feature allow to automatically turn on the test mode prior to the receiver stress test and change test patterns. This allows to easily adapt the test for specific silicon implementations or for changing the test pattern for debugging purposes.

Integrated signal analysis features of the error detector allow to measure and calibrate the test setup without additional instruments for measuring jitter, amplitude etc.

ENA network analyzer E5071C

The E5071C network analyzer offers the highest RF performance and fastest speed in its class, with a wide frequency range and versatile functions. The E5071C is the ideal solution for manufacturing and R&D engineers evaluating RF components and circuits for frequency range up to 20 GHz.

The USB 3.0 Cable Compliance MOI requires option 010 and one of 480/485/4K5.



USB 3.0 Receiver Test Software

The Keysight receiver test software N5990A option 102 covers both, USB 2.0 and USB 3.0. It complements the U7243A compliance test suite with the receiver compliance, jitter tolerance, sensitivity and constant parameter stress tests. For USB 3.0 receiver testing N5990A option 102 controls the Keysight J-BERT N4903A/B and additional instruments. N5990A option 202 is the interface to the U7243A, providing a consolidated test report.

Ellisys USB Explorer 280 Protocol Analyzer

Keysight recommends Ellisys USB Explorer 280 protocol analyzer for unsurpassed Superspeed analysis. See www.ellisys.com

myKeysight

www.keysight.com/find/mykeysight
A personalized view into the information most relevant to you.

www.lxistandard.org
LAN eXtensions for Instruments puts the power of Ethernet and the Web inside your test systems. Keysight is a founding member of the LXI consortium.

www.pxisa.org
PCI eXtensions for Instrumentation (PXI) modular instrumentation delivers a rugged, PC-based high-performance measurement and automation system.

Three-Year Warranty
www.keysight.com/find/ThreeYearWarranty
Keysight's commitment to superior product quality and lower total cost of ownership. The only test and measurement company with three-year warranty standard on all instruments, worldwide.

Keysight Assurance Plans
www.keysight.com/find/AssurancePlans
Up to five years of protection and no budgetary surprises to ensure your instruments are operating to specification so you can rely on accurate measurements.

Keysight Channel Partners
www.keysight.com/find/channelpartners
Get the best of both worlds: Keysight's measurement expertise and product breadth, combined with channel partner convenience.

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India	1 800 112 929
Japan	0120 (421) 345
Korea	080 769 0800
Malaysia	1 800 888 848
Singapore	1 800 375 8100
Taiwan	0800 047 866
Other AP Countries	(65) 6375 8100

Europe & Middle East

Austria	0800 001122
Belgium	0800 58580
Finland	0800 523252
France	0805 980333
Germany	0800 6270999
Ireland	1800 832700
Israel	1 809 343051
Italy	800 599100
Luxembourg	+32 800 58580
Netherlands	0800 0233200
Russia	8800 5009286
Spain	0800 000154
Sweden	0200 882255
Switzerland	0800 805353
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United Kingdom	0800 0260637

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