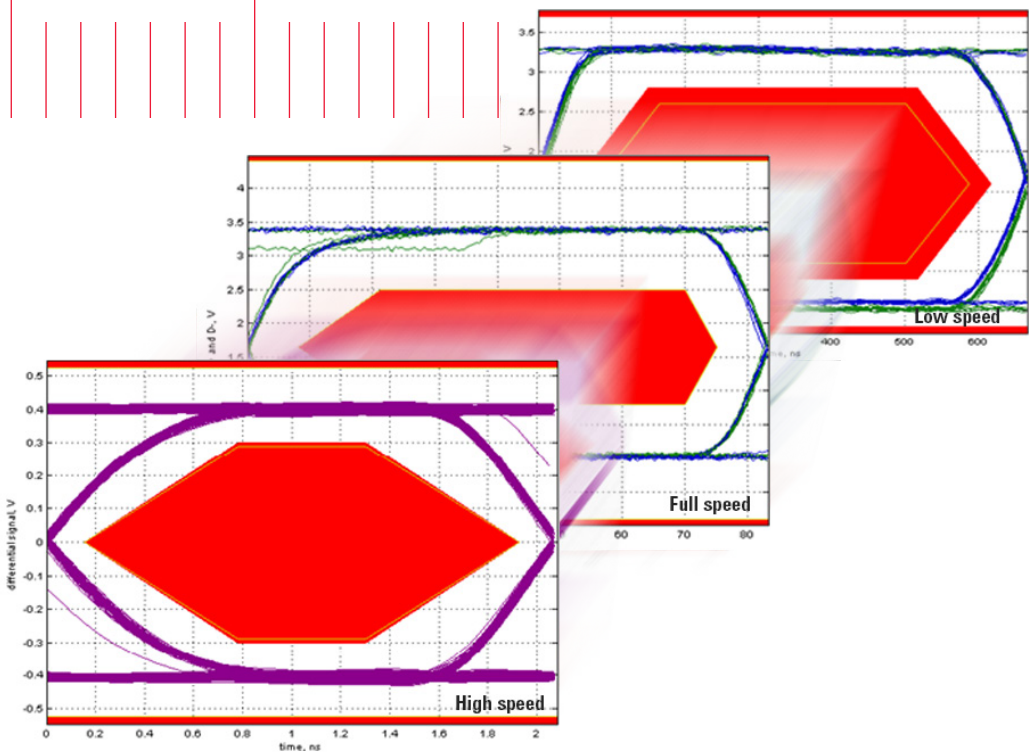
Keysight Technologies

Physical Layer Testing of the USB 2.0 Serial Bus

Using InfiniiVision 6000 X-Series and Infiniium Series Oscilloscopes

Application Note



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Introduction

The Universal Serial Bus was developed and standardized by a group of leading companies from the computer and electronics industries in 1995. These companies also formed the USB Implementers Forum, Inc. (USB-IF) as a non-profit corporation to publish the specifications and provide a support organization and forum for the advancement and adoption of USB technology.

USB 2.0 Overview

USB 2.0, which includes high-speed (480 Mbps), full-speed (12 Mbps) and low-speed(1.5 Mbps), is used today in a broad range of computers as well as embedded designs. One example of an embedded design is the automotive charging and sync USB port available in a variety of newer vehicles. Beyond traditional PC computers, most other types of electronic products, such as medical equipment or industrial control systems, include USB interfaces as well.

With almost 20 years of functional interoperability experience behind it, any new products shipped must meet the user's expectations that it will just work. This is why testing and debugging USB designs using high-speed, full-speed or low-speed USB 2.0 interfaces is critical to ensure reliability of operation and meet end user expectations.

To complement the USB specification in real products, the USB-IF maintains a compliance program that provides reasonable measures of acceptability. Products that pass compliance testing have the right to license the USB-IF certified USB Logo. One of the key components of USB compliance testing is physical layer testing. This has helped USB product success and acceptance by creating a very stable and interoperable ecosystem. Since that time USB has become ubiquitous. Over 10 billion USB products have shipped since its introduction and it has effectively replaced all other external IO interfaces. There are an estimated 4 billion USB products shipped annually 3/4 of them (3 billion) are using USB 2.0.

USB-IF physical layer compliance certification is typically required by computer OEMs for suppliers of USB devices and silicon chip-sets. However, full compliance certification testing is typically not a requirement for embedded products. Nonetheless, R&D testing and verification of physical layer characteristics of embedded designs with integrated USB interfaces is extremely important to ensure reliable operation of end-products. Simply selecting USB components, integrating them into an embedded design, and then hoping that everything functions is not good enough. Even if the system appears to function, how much margin does it have? Or how does it perform under various environmental conditions such as temperature or humidity?

This application note begins with a discussion of measurement requirements for the USB 2.0 serial bus. We then discuss how both the Keysight Technologies, Inc. 6000 X-Series and Infiniium Series oscilloscopes address these challenges and which scope is the best choice for the type of testing and test coverage the product developer needs to perform.

Testing USB 2.0 Interfaces

The Universal Serial Bus (USB) specification defines the product design targets at the level of interfaces and mechanisms. To complement the specification and enable measurement of compliance in real products, the USB-IF has a compliance program that provides measures of acceptability. Products that pass these test requirements are added to the integrators list and have the right to license the USB-IF logo. The primary goal of the compliance program is to help ensure various USB products will interoperate and thus continue the success of USB technologies.

There are 4 categories of testing required for certification testing.

– Full-Speed/Low-Speed Electrical Tests

– High-Speed Electrical Tests

– Interoperability Tests

– Functional Tests

We are only going to talk about the first two, which are about the electrical tests. Let's begin by describing the primary USB electrical test requirements. The key parametric for USB testing is the eye diagram test as seen in Figure 1.

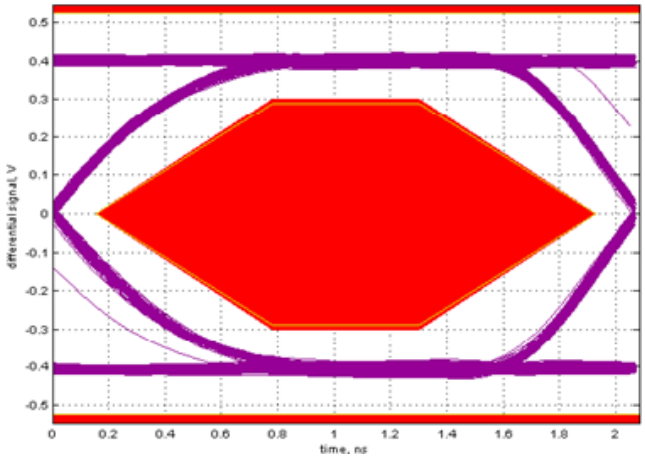


Figure 1. An example of a high speed eye diagram as tested on a Keysight oscilloscope, the eye diagram test is the key parametric for USB testing.

Many electrical performance measures can be verified quickly using an eye diagram test. If the signal frequency is too fast or slow, has high or low amplitudes, too noisy, or poor edge shapes this can be observed from the eye diagram. An open, clean eye pattern corresponds to good signal integrity. A closed or noisy eye can indicate marginal or failing signal integrity which can cause the product to fail to interoperate with other products.

In general, the eye diagram test is a good "reality check" to ensure signal quality standards are met before releasing a product into production or submitting a product for official certification testing to a USB-IF test lab or compliance test event. An eye diagram that passes the USB-IF signal quality test requirements is also a good indication that the product under test will be able to function electrically with existing products on the market. Other product design or implementation issues could result in failing interoperability or functional tests, but passing the electrical test is good foundation for a reliable product.

Additional testing is necessary to fully validate that your product meets all the electrical requirements of the USB 2.0 specification beyond just the eye diagram test. It should be understood that just passing the eye test does not give full confidence that the product will pass the full USB-IF compliance program tests, of which there are many more.

6000 X-Series USB Signal Quality Test Capabilities

With the addition of the USB 2.0 Signal Quality Test option (DSOX6USBSQ) licensed on a Keysight InfiniiVision 6000 X-Series oscilloscope, the following signal quality tests based on USB-IF compliance standards can be performed automatically:

- Real-time eye test
- Consecutive, paired JK, and paired KJ jitter
- Sync test
- Cross-over voltage (low- and full-speed only)
- EOP bit-width
- Signaling rate
- Edge monotonicity
- Rise/fall edge rate
- Edge rate match (low- and full-speed only)
- HTML pass/fail report generation

After running a USB 2.0 Signal Quality test, a complete test report with color-coded pass/fail measurement results are shown on the scope's display with a scroll-bar to view all tests and screen images, as shown in Figure 2. In addition, the complete test report can be saved as a HTML file for test documentation purposes. Figure 2 shows an example test report from a far-end, high-speed device signal quality test.

These test are a good choice for that visual signal quality check, if you are integrating certified USB silicon. The digital timing and control parts of USB functions should be within specification. However if you are not careful with board layout or component placement you could suffer signal integrity issues. If the electrical path is bad you will have interoperability problems with other products.

So in the case where the designer is using proven silicon and just needs to spot check the signal integrity in a "pre-compliance" test scenario then the InfiniiVision 6000 X-Series oscilloscope is a good choice and the best value for the cost.

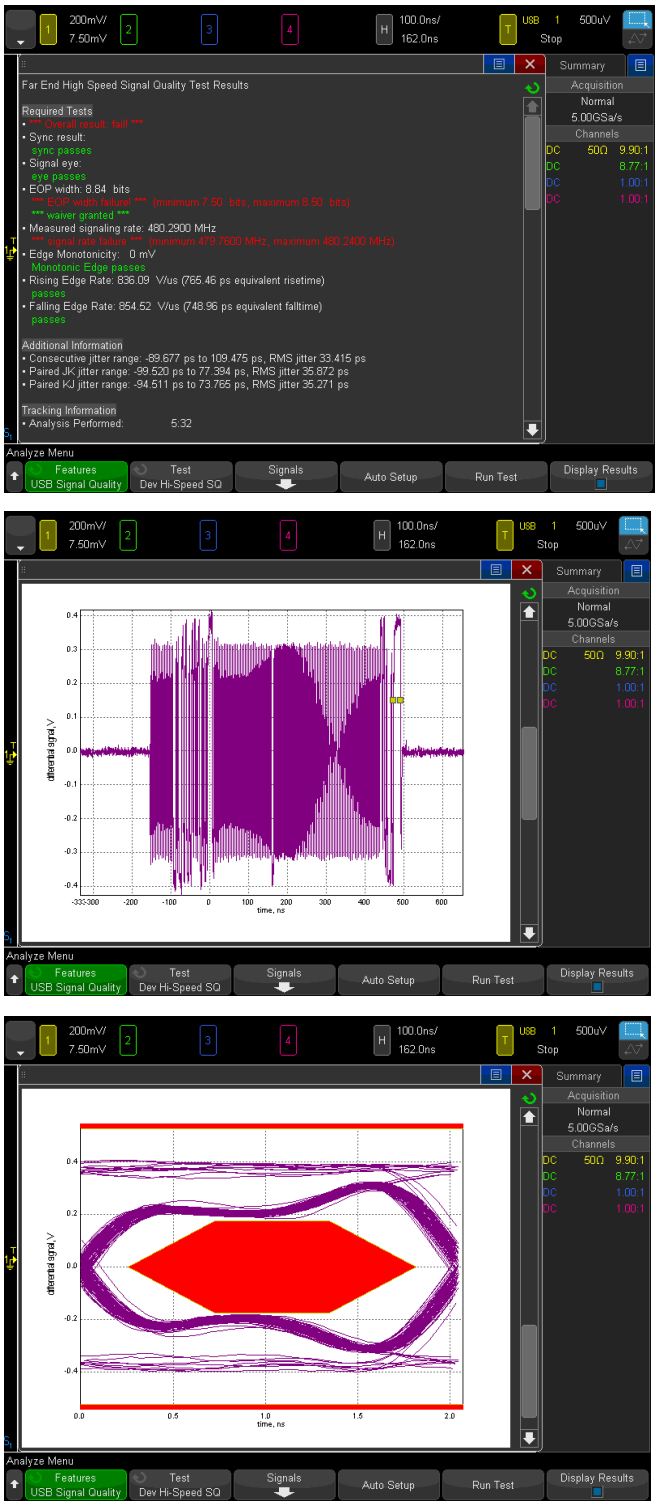


Figure 2. USB 2.0 Signal quality tests run on an InfiniiVision oscilloscope

Infiniium Series USB 2.0 Compliance Test Application Capabilities

For Infiniium Series oscilloscopes, the N5416A USB 2.0 compliance test software can be used to run the same signal quality tests. The application also creates a full test report and project file that can be saved and re-opened later to add additional tests or review previous results.

This solution is neccessary for new silicon designs or designs using silicon that is not certified by the USB-IF. For example, logical or timing latency issues, like inter-packet gap, could cause the device to fail to operate with other products in the market. Figure 3 shows the test results output for inter-packet gap testing run using the N5416A USB 2.0 compliance test software.

Official certification testing requires dozens of additional tests beyond signal quality host, hub and device testing. In addition to full automation of these tests the N5416A USB 2.0 compliance test software also provides detailed instructions and connection diagrams built into the compliance test software. It also includes support for full coverage testing of USB OTG (On-The-Go), embedded host testing.

Infiniium Series oscilloscopes provide up to 8 GHz bandwidth with sampling up to 20 GS/s. These scopes also provide the deepest memory in the industry with up to 800 Mpts of acquisition memory. The platform is based on a Windows operating system that has been optimized for advanced waveform analysis of high-speed digital designs. This class of oscilloscope features fully automated compliance testing options for dozens of standard industry serial interfaces including USB 2.0. This is the same test solution used at USB-IF compliance workshops and test labs worldwide to certify USB 2.0 products.

The N5416A contains the complete suite of tests required to verify you meet the full USB-IF compliance testing requirements.

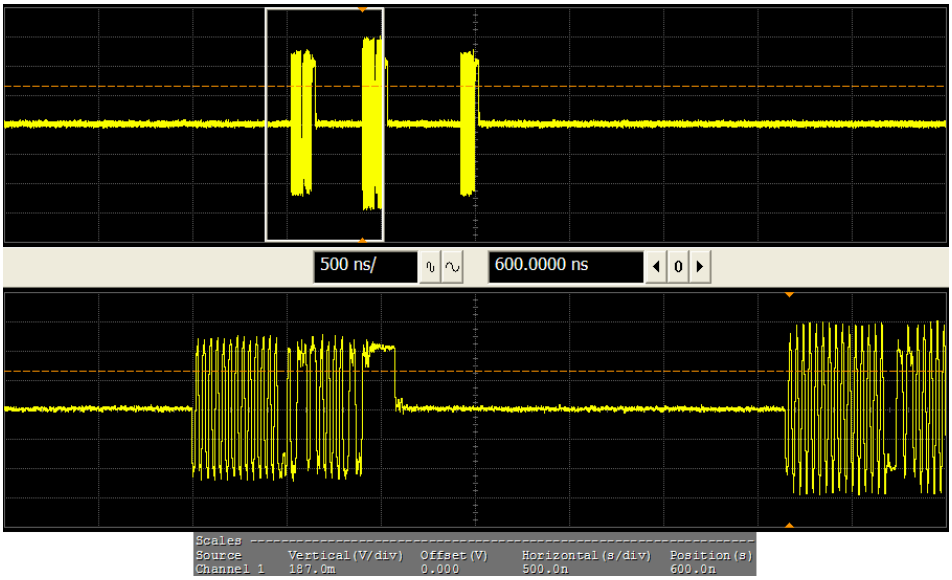


Figure 3. Inter-packet gap test with USB 2.0 compliance test software on an Infiniium Series oscilloscope

Infiniium Series USB 2.0 Compliance Test Application Capabilities (continued)

Table 1. A representation of what a user would see after running the full compliance application of the N5416A application option on any one of the Infiniium oscilloscopes

Summary of Results

Margin Thresholds	
Warning	< 2 %
Critical	< 0 %

Pass	# Failed	# Trials	Test Name	Actual Value	Margin	Spec Range
✓	0	1	EL_2 EL_4 EL_5 Data Eye and Mask Test	Pass	100.0 %	Overall Data Eye Test = Pass
✓	0	1	EL_6 Device Rise Time	Pass	100.0 %	Overall Rise Time Test = Pass (>400ps)
✓	0	1	EL_6 Device Fall Time	Pass	100.0 %	Overall Fall Time Test = Pass (>400ps)
✓	0	1	EL_7 Device Non-Monotonic Edge Test	Pass	100.0 %	Non-monotonic Edge = Pass
✓	0	1	EL_21 Device Sync Field Length Test	66.646ns	47.5 %	65.600ns <= VALUE <= 67.800ns
✓	0	1	EL_25 Device EOP Length Test	16.843ns	40.8 %	15.600ns <= VALUE <= 17.700ns
✓	0	1	EL_22 Measure Interpacket Gap Between Second and Third Packets	242.771ns	40.9 %	16.640ns <= VALUE <= 399.400ns
✓	0	1	EL_22 Measure Interpacket Gap Between First and Second Packets	248.692ns	39.4 %	16.640ns <= VALUE <= 399.400ns
✓	0	1	EL_28 Measure Device CHIRP-K Latency	1.503572ms	25.0 %	2.500µs <= VALUE <= 6.000000ms
✓	0	1	EL_29 Measure Device CHIRP-K Duration	2.000ms	16.7 %	1.000ms <= VALUE <= 7.000ms
✓	0	1	EL_31 Host Hi-Speed Terminations Enable and D+ Disconnect Time	3.644µs	0.7 %	10ns <= VALUE <= 500.000µs
✓	0	1	EL_38 EL_39 Device Suspend Timing Response	3.001ms	0.8 %	3.000ms <= VALUE <= 3.125ms
✓	0	1	EL_40 Device Resume Timing Response	Pass	100.0 %	Presence of high-speed SOF packets detected = Pass
✓	0	1	EL_27 Device CHIRP Response to Reset from Hi-Speed Operation	3.503ms	13.9 %	3.100ms <= VALUE <= 6.000ms
✓	0	1	EL_28 Device CHIRP Response to Reset from Suspend	1.503576ms	25.0 %	2.500µs <= VALUE <= 6.000000ms
✗	1	1	EL_8 Device J Test	Failed D+	100.0 %	J Test = pass
✗	1	1	EL_8 Device K Test	Failed D-	100.0 %	K Test = pass
✗	1	1	EL_9 Device SE0_NAK Test	Failed D-	100.0 %	SE0NAK Test = pass
✓	0	1	Upstream Full Speed Signal Quality Test	Pass	100.0 %	Overall Data Eye Test = Pass
✓	0	1	Upstream Full Speed Rise Time Test	Pass	100.0 %	Information
✓	0	1	Upstream Full Speed Fall Time Test	Pass	100.0 %	Information
✓	0	1	Inrush Current Test	pass	0.0 %	Overall Inrush Current Test = Pass
✓	0	1	VBUS Before Enumerate	0.000V	100.0 %	VALUE <= 400mV
✓	0	1	D+ Before Enumerate	0.000V	100.0 %	VALUE <= 400mV
✓	0	1	D- Before Enumerate	0.000V	100.0 %	VALUE <= 400mV
✓	0	1	VBUS After Enumerate	0.000V	100.0 %	VALUE <= 400mV
✓	0	1	D+ After Enumerate	0.000V	100.0 %	VALUE <= 400mV
✓	0	1	D- After Enumerate	0.000V	100.0 %	VALUE <= 400mV

Infiniium Series USB 2.0 Compliance Test Application Capabilities (continued)

The following table summarizes the features of Keysight's various USB test analysis options in InfiniiVision 6000 X-Series and Infiniium oscilloscopes:

Table 2. USB Testing coverage comparison

USB measurement	Signal integrity testing with InfiniiVision 6000X DSOX6USBSQ option	Complete USB-IF electrical compliance testing with Infiniium S-Series N5416A option
EL_2 EL_4 EL_5 Data Eye and Mask Test High speed SQ	√	√
Consecutive, paired JK, and paired KJ jitter	√	√
Full and Low speed signal quality		
Sync test	√	√
Cross-over voltage (low- and full-speed only)	√	
EOP bit-width	√	√
Signaling rate	√	√
EL_6 Device Rise and Fall Time	√[1]	√
Edge rate match (low- and full-speed only)	√	√
HTML pass/fail report generation	√	√
EL_7 Device Non-Monotonic Edge Test	√	√
EL_22 Interpacket Gap Tests		√
EL_28 Chirp-K Latency		√
EL_29 Device CHIRP-K Duration		√
EL_31 Host Hi-Speed Terminations Enable and D+ Disconnect Time		√
EL_38 EL_39 Device Suspend Timing Response		√
EL_40 Device Resume Timing Response		√
EL_27 Device CHIRP Response to Reset from Hi-Speed Operation		√
EL_28 Device CHIRP Response to Reset from Suspend		√
EL_8 Device J Test		√
EL_8 Device K Test		√
EL_9 Device SE0_NAK Test		√
Inrush Current Test		√
Drop/Droop Vbus tests		√
VBus Backdrive tests		√

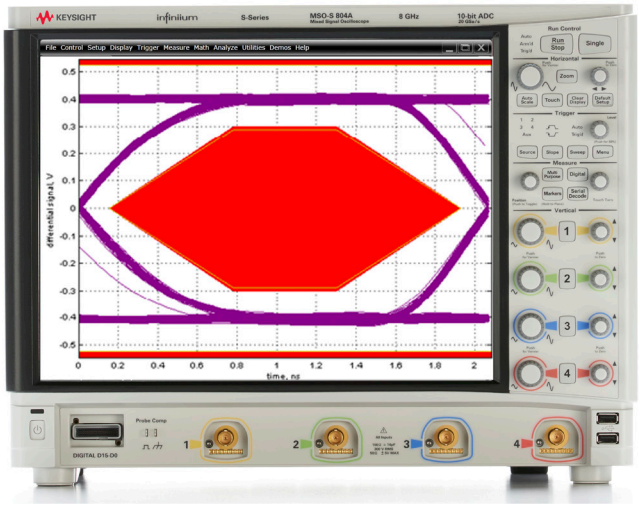
1. To accurately measure USB 2.0 rise and fall times with less than 10% error for sub 500 ps edges the measurement BW must be at least 2.5 GHz as required for official USB-IF compliance testing.

Choosing the Right Oscilloscope Platform for Your USB Measurements

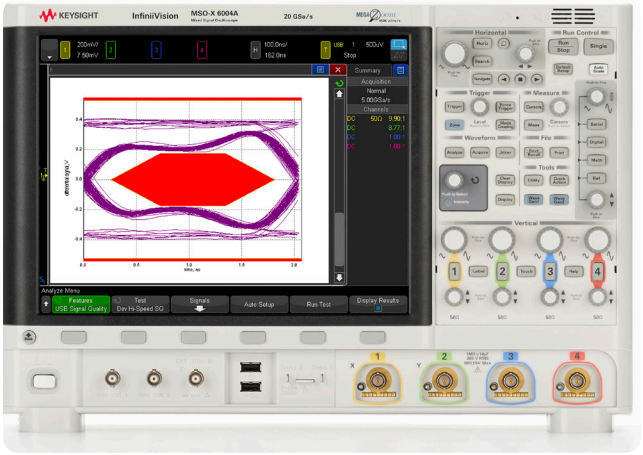
So which oscilloscope platform from Keysight best fits your USB measurement needs; the InfiniiVision 6000 X-Series or the Infiniium Series? This depends on your oscilloscope performance requirements (bandwidth, sample rate, and memory depth), your use-model (will you use it more for debug or in depth analysis), your budget and the level of USB testing you need to do.

The Keysight InfiniiVision 6000 X-Series oscilloscope provides up to 6 GHz bandwidth with sampling up to 20 GSa/s and a standard memory depth of 4 M points. This platform has the required specifications to perform USB signal quality measurements and could be used to measure many of the other typical USB tests with manual setup and configuration, but will not cover the full USB-IF test suite.

If you need to fully validate your design meets all of the requirements of the USB 2.0 electrical and test specifications then an Infiniium Series oscilloscope is the best choice for your testing needs



The Infiniium S-Series oscilloscope



The Keysight InfiniiVision 6000 X-Series oscilloscope

Related Literature

Publication title	Publication type	Publication number
Keysight InfiniiVision 6000 X-Series Oscilloscopes (1 GHz to 6 GHz)	Data sheet	5991-4087EN
Keysight Infiniium S-Series Oscilloscopes (500 MHz to 8 GHz)	Data sheet	5991-3904EN
N5416A and N5417A USB Compliance Test Software for Infiniium Oscilloscopes	Data sheet	5989-4044EN
Serial Bus Options for InfiniiVision X-Series Oscilloscopes	Data sheet	5990-6677EN
DSOX4USBSQ/DSOX6USBSQ USB 2.0 Signal Qualify Test Option	Data sheet	5991-1762EN
USB 2.0 Compliance Testing with Infiniium Oscilloscopes	Application note	5988-6219EN
Characterizing Hi-speed USB 2.0 Serial Buses in Embedded Designs	Application note	5991-1148EN

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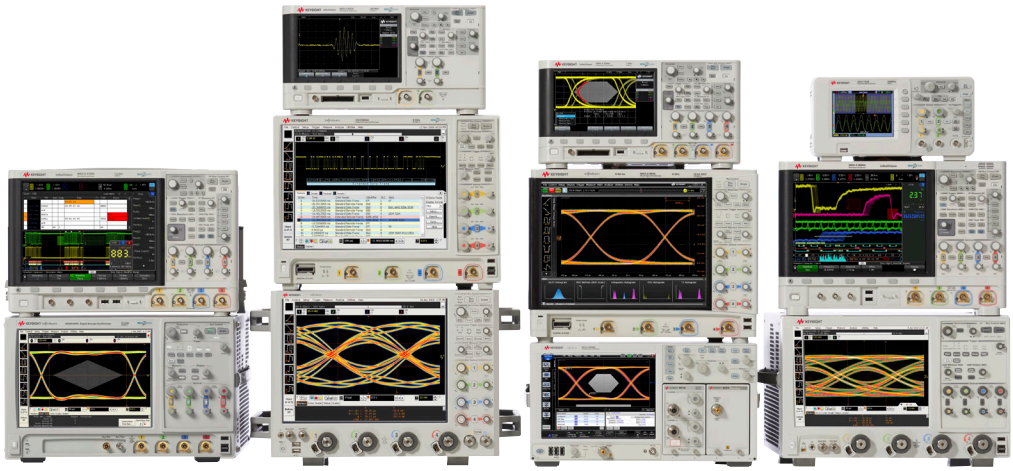

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