

# Keysight Technologies

## Characterizing Hi-Speed USB 2.0 Serial Buses In Embedded Designs

### Application Note





## Introduction

The hi-speed USB 2.0 serial bus is used today in a broad range of computer as well as embedded designs. One good example of an embedded design is the oscilloscope itself, which often includes USB interfaces for connectivity, mouse operation, and external data storage. Most other types of electronic products, such as medical equipment or industrial control systems, include USB interfaces as well. The USB 2.0 serial interface has been rapidly replacing older RS-232 serial interfaces in embedded designs.

Although USB-IF physical layer compliance certification is typically required by computer OEMs for suppliers of USB devices and silicon chip-sets, compliance certification 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?

When debugging and verifying the performance of hi-speed USB 2.0 designs, the Keysight Technologies, Inc. InfiniiVision 4000 and 6000 X-Series oscilloscopes offer several advantages over many higher performance oscilloscopes that are typically used for full compliance testing. One obvious advantage is the lower price of the 4000 and 6000 X-Series oscilloscopes. But the advantages of the scope go beyond just price. Although many higher performance Windows-based scopes have been optimized for advanced waveform analysis, Keysight's InfiniiVision 4000 and 6000 X-Series oscilloscopes have been optimized for signal visualization and debug.

This application note begins with a discussion of probing the hi-speed USB 2.0 serial bus using Keysight's N2750A InfiniiMode Series differential active probe. We then show some of the unique debugging tools and capabilities of the Keysight 4000 and 6000 X-Series portable bench-top scopes that can help you get your embedded designs to market faster.

## Probing the hi-speed USB 2.0 differential bus

Since the hi-speed USB 2.0 bus is differential, a differential active probe must be used to capture and analyze signals. Keysight recommends using the N2750A InfiniiMode Series of differential active probes shown in Figure 1. This family of differential active probes comes in three different bandwidth models ranging from 1.5 GHz to 6 GHz. Even if using the lowest-priced 1.5-GHz model (N2750A), which actually has a typical bandwidth of 2.0 GHz, the combined system bandwidth (including a 1.5-GHz bandwidth scope) is typically 1.5 GHz. This is the USB-IF's minimum recommended oscilloscope bandwidth for hi-speed USB applications.

The N2750A Series probe is more than just a differential probe. With the press of a button on the probe, you can quickly toggle between viewing the differential signal, high-side (D+) relative to ground, low-side (D-) relative to ground, or the common-mode signal. Although ultimately it is the quality of the differential signal that really matters, if signal integrity issues do exist on the differential bus, they can often be caused by issues such as system noise coupling into just one side of the bus or perhaps improper PC board layout and/or improper terminations related to just one side of the bus.

Figure 2 shows an example of viewing the hi-speed USB bus differentially. Note the significant level of noise on this differential signal. Although it can't be shown in this document, the noise was intermittent; sometimes the captured packets were relatively noise free, and sometimes they contained a significant level of noise as shown in this particular screen image.

With the press of a button on the Keysight InfiniiMode probe, we can view just the high-side (D+) of the USB bus as shown in Figure 3. In this example, the noise level on the D+ side of the bus was acceptable and measured significantly less than the original differential bus measurement.



Figure 1: Keysight's InfiniiMode N2750A Series differential active probe.



Figure 2: Capturing the hi-speed USB differential signal.



Figure 3: Capturing just the USB high-side (D+) of the differential bus.

## Probing the hi-speed USB 2.0 differential bus

If we press the InfiniiMode probe button once again, we can then view just the low-side (D-) of the USB bus as shown in Figure 4. The intermittent noise reappeared when monitoring this side of the bus. Noise is evidently coupling into just one side of our differential USB bus.

Lastly, we can also view the common-mode signal of this hi-speed USB bus as shown in Figure 5. This screen image shows the common-mode DC offset of each packet, along with common-mode noise and signal coupling.

The next step in this debugging example was to attempt to discover the source of the noise and also try to determine why it coupled into just one side of the bus. After further troubleshooting, it was determined that the source of the noise was coming from the embedded system's switching power supply. Figure 6 shows a second channel of the oscilloscope used to simultaneously capture the output of the switching power supply. We can now see a clear correlation between the noise on captured USB packets (yellow trace) with the power supply's switching noise/ripple (pink trace). Note that the upper half of the scope's display shows waveforms using a wider timebase setting (1  $\mu$ s/div), while the lower half of the display shows a zoomed-in expansion (30 ns/div) on a single packet with noise.

The reason the noise intermittently coupled onto USB packets was because the much lower frequency of switching noise was not synchronous with the transmission of USB traffic. It was discovered that the reason the noise coupled into just one side of the differential bus was due a poor PC board layout and grounding.

Capturing and observing our hi-speed USB signal in four different probing configurations, shown in the above debugging example, was achieved without moving any of the probe connections. To perform the same measurements using conventional differential active probes would either require using multiple active probes connected in parallel — which could induce excessive loading, as well as being an expensive test solution — or require moving probe connections between each measurement, which would be a time-consuming measurement process.



Figure 4: Capturing just the USB low-side (D-) of the differential bus.

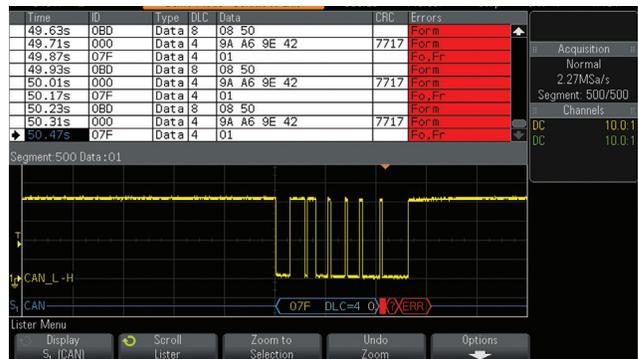


Figure 5: Capturing the common-mode signals on the differential bus.



Figure 6: Poor PC board layout resulted in power supply switching noise coupling into one side of the hi-speed USB differential bus.

## USB triggering and hardware-based decode

Although USB serial bus protocol analyzers can provide a higher abstraction level of protocol decode, they tell you nothing about the quality of signals that produce each USB packet. With the addition of the hi-speed USB 2.0 decode and trigger option (DSOX4USBH or DSOX6USBH), the 4000 and 6000 X-Series oscilloscopes cannot only trigger on a broad range of USB specific packet types (handshake, token, data, etc.) and errors, but the scope also provides a time-correlated decode trace of each packet below captured waveforms so you can directly compare the quality of waveforms that produce each decoded byte. In addition, the scope can also display a tabular list of multiple and consecutively captured and decoded packets in the upper half of the scope's display as shown in Figure 7.

There is a big difference between the protocol decode technique implemented in Keysight's 4000 and 6000 X-Series oscilloscopes as compared to decoding in other oscilloscopes on the market today. The 4000 and 6000 X-Series oscilloscopes utilize hardware-based decoding as opposed to conventional oscilloscope software-based decoding. This means that the scope remains responsive and fast when decoding is turned on. And, with a virtual real-time update of the USB decode trace; the scope has a much higher probability of detecting infrequent USB errors such as PID errors or CRC errors as compared to other oscilloscopes that utilize software-based decoding.



Figure 7: Hardware-based decoding enhances the scope's probability of capturing hi-speed USB 2.0 errors.

## Fast waveform update rate

Probably the biggest advantage of Keysight's 4000 and 6000 X-Series oscilloscope to test and debug embedded hi-speed USB designs is the extremely fast and uncompromised waveform update rate of this scope. The 4000 X-Series scope can update waveforms as fast as 1,000,000 waveforms per second even with the scope's hardware-based USB protocol decoding turned on. Most other oscilloscopes on the market today that support decoding hi-speed USB buses update waveforms in the range of hundreds of updates per second or less when software-based decoding is turned on.

Not only do fast waveform updates enhance the responsiveness and usability of the scope, but they also provide you with a dynamic view of repetitive and overlaid waveforms as shown in Figure 8. But, more importantly, fast waveform updates enhance the scope's probability of capturing random and infrequent events that may be problematic in your hi-speed USB system designs. If an infrequent glitch or amplitude shift occurs within a USB packet as shown in Figure 9, Keysight's 4000 and 6000 X-Series oscilloscopes have a probability that is tens of thousands times higher than other oscilloscopes at capturing and displaying the random anomaly.

To learn more about the importance of fast waveform update rates, download Keysight's application note "Fast Waveform Update Rates Enhance the Probability of Capturing Elusive Events" listed at the end of this document.

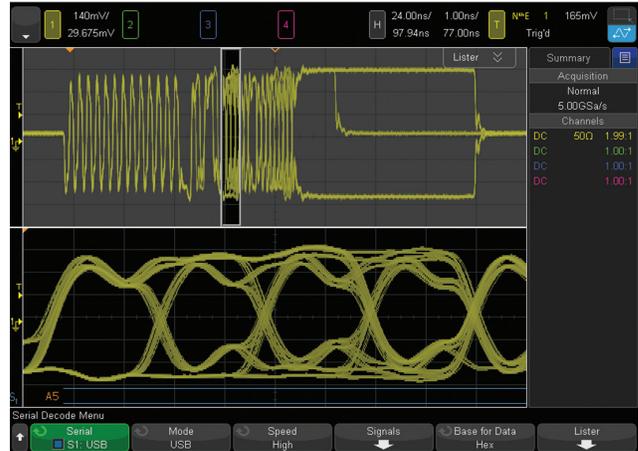


Figure 8: Fast waveform and decode update rate provides a near real-time view of the dynamic behavior of your hi-speed USB signals.

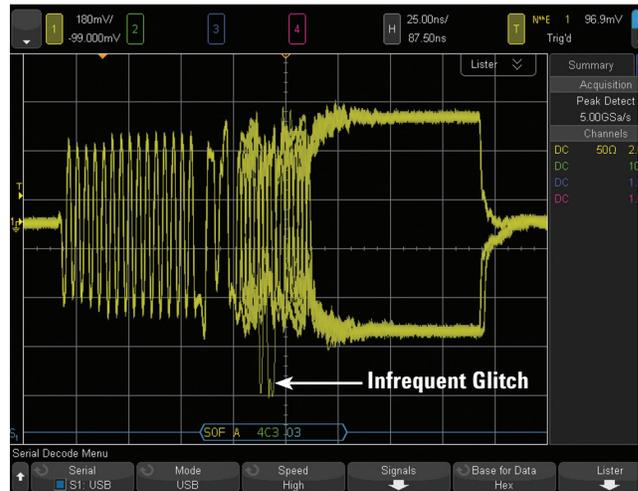


Figure 9: Fast waveform update rates enhance the scope's probability of capturing random and infrequent events.

## InfiniiScan zone trigger

Once you are able to observe random and infrequent signal integrity problems within your USB-based designs using the scope's extremely fast waveform update rate, uniquely synchronizing the scope's display on just anomalous and problematic events is the next trick. Although this scope comes with a broad range of signal-violation triggering capabilities, such as setup & hold time trigger, runt trigger, etc., this scope's InfiniiScan Zone Trigger capability is typically the quickest and easiest way to trigger on a signal integrity problem. Once you can trigger on the problem signal, you can then look for correlation to other signals in your system.

Basically, if the scope's fast waveform update rate (up to 1,000,000 waveforms/sec) reveals random and infrequent signal anomalies, such as the infrequent glitch shown in Figure 9, then InfiniiScan Zone Trigger can trigger on it. Simply draw a "zone box" in the area of the anomalous signal behavior using the scope's touch screen, and then select that the captured waveform "must intersect" that zone in order to be uniquely displayed as shown in Figure 10.

Unlike much slower software-based zone type triggering that may be available in other higher performance and more expensive oscilloscopes; InfiniiScan Zone Trigger is based on hardware technology with an update rate of up to 200,000 waveforms per second when Zone is on.

When using InfiniiScan Zone Trigger, the scope first pre-qualifies acquisitions based on any conventional oscilloscope trigger condition such as simple edge trigger or even a specific USB packet trigger condition. The scope then triggers on waveforms that meet the graphical zone qualification criteria. Basically, if you can see infrequent anomalous events on the scope's display while the instrument is updating at 1,000,000 waveforms per second, then zone trigger has a high probability of uniquely triggering on the anomaly with a hardware-based InfiniiScan update rate of 200,000 waveforms per second.

To learn more about InfiniiScan Zone Trigger, download Keysight's application note "Triggering on Infrequent Anomalies using InfiniiScan Zone Trigger" listed at the end of this document.



Figure 10: InfiniiScan Zone Trigger can be used to uniquely trigger on infrequent hi-speed USB signal problems.

## Segmented memory acquisition

USB packets are often widely separated in time. To capture multiple and consecutive packets while sampling at a sufficiently high sample rate typically requires very deep acquisition memory. But, most of the scope's memory is often wasted on capturing signal idle time between packets-of-interest. Not only are scopes with very deep acquisition memory (hundreds of Mega bytes) expensive, but wading/searching through captured data to isolate specific packets-of-interest can be difficult and time-consuming.

Performing a segmented memory acquisition using Keysight's 4000 or 6000 X-Series oscilloscope is a much more efficient and cost-effective method to capture multiple and selective USB packets — and without wasting valuable acquisition memory on signal idle time between events.

Figure 11 shows an example of capturing 25 consecutive Data 0 packets during enumeration after hot-plugging a USB hi-speed device for a total, but selective, acquisition time of nearly 650 milliseconds. Capturing this equivalent timespan of serial data using conventional oscilloscope acquisition memory, while still sampling at 5 GSa/s, would require more than 3 Gigabytes of memory. This much acquisition memory is not yet available in any oscilloscope on the market today. And, if it was, it would be a very expensive solution.

To learn more about Segmented Memory applications, download Keysight's application note "Using Oscilloscope Segmented Memory for Serial Bus Applications" listed at the end of this document.

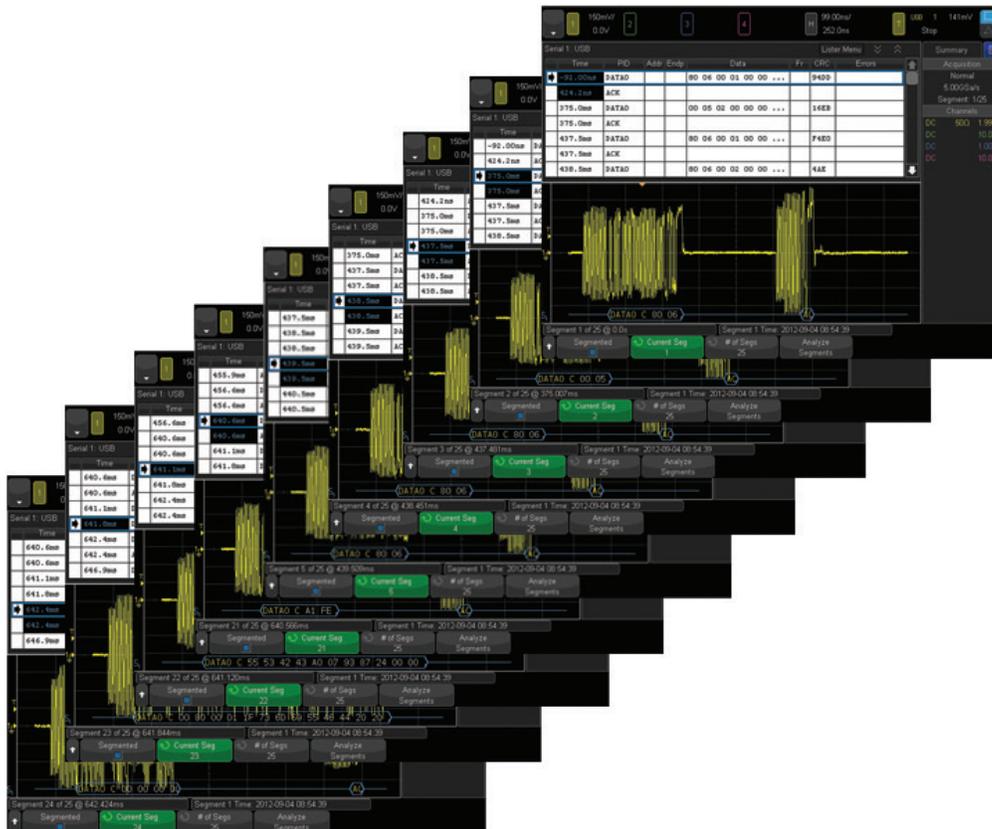


Figure 11: Using Segmented Memory Acquisition to capture more selective packets over a longer timespan.

## USB 2.0 signal quality pre-compliance testing

Although USB-IF physical layer compliance testing and certification is not normally performed on embedded electronic products with USB 2.0 interfaces, for reliability purposes designers of embedded systems often need to test the physical layer of their designs based on USB-IF specified standards as a “reality check” to insure signal quality standards are met before releasing their products into production.

With the addition of the USB 2.0 Signal Quality Test option (DSOX4USBSQ or DSOX6USBSQ) licensed on a Keysight InfiniiVision 4000 or 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 12.

In addition, the complete test report can be saved as a HTML file for test documentation purposes. Figure 13 shows an example test report from a far-end, hi-speed device signal quality test. In this test, the device marginally failed the EOP bit-width test, but was granted a waiver.

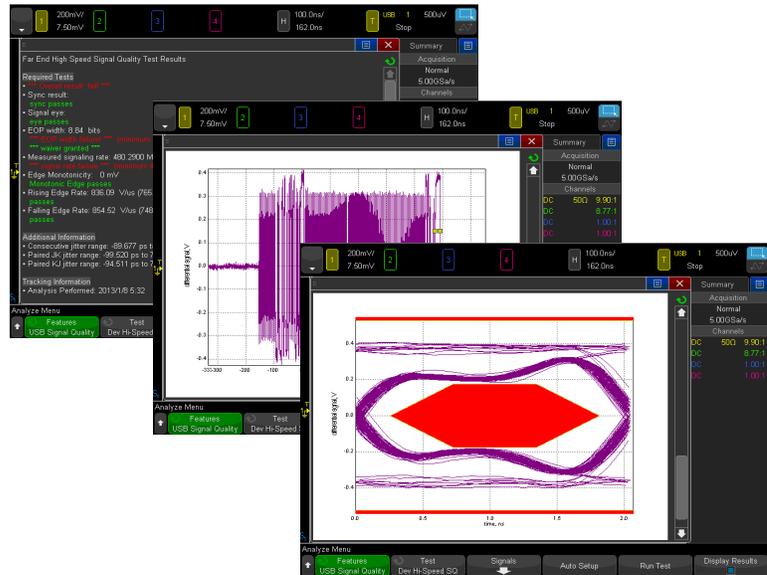


Figure 12: Scrollable on-screen Signal Quality test report.

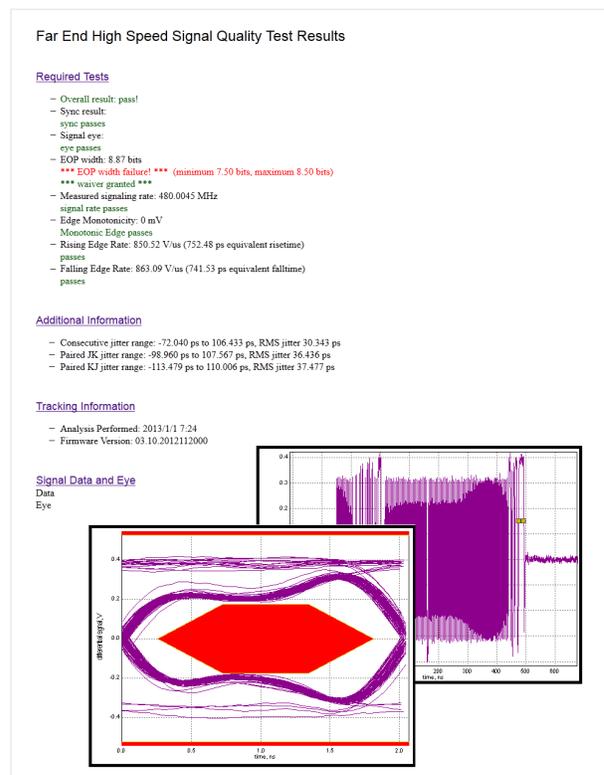


Figure 13: USB 2.0 Signal Quality test report in HTML format.

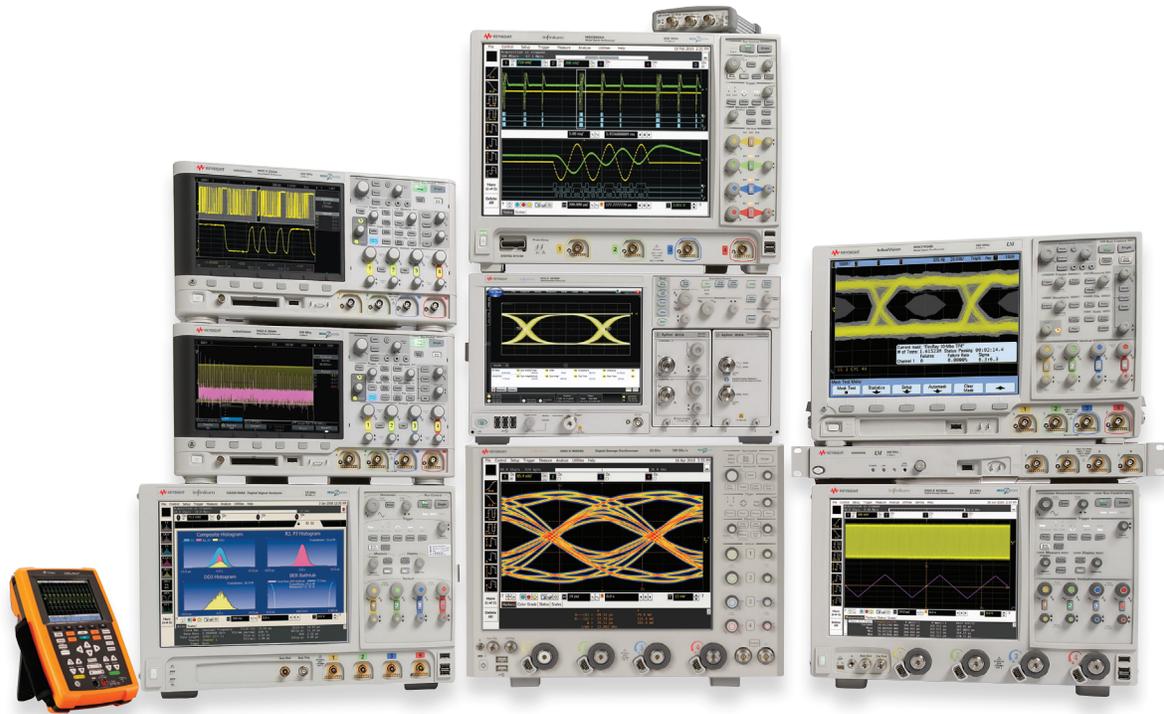
## Summary

Testing and debugging embedded systems that include hi-speed USB 2.0 interfaces is critical to insure reliability of operation. Keysight's InfiniiVision 4000 and 6000 X-Series oscilloscopes with the N2750A InfiniiMode Series differential active probe is the most cost effective solution on the market today. This oscilloscope family also provides some unique capabilities that can help you test and debug your USB designs faster including:

- Fast waveform update rates (up to 1,000,000 waveforms/sec)
- Hardware-based USB protocol decoding
- InfiniiScan Zone Trigger
- Segmented Memory acquisition
- Automated USB 2.0 signal quality testing (with DSOX4USBSQ or DSOX6USBSQ option)

## Related literature

Publication title	Publication type	Publication number
<i>InfiniiVision 4000 X-Series Oscilloscopes</i>	Data Sheet	5991-1103EN
<i>InfiniiVision 6000 X-Series Oscilloscopes</i>	Data Sheet	5991-4087EN
<i>N2750A InfiniiMode Series Differential Active Probe</i>	Data Sheet	5991-0560EN
<i>DSOX4USBSQ/DSOX6USBSQ USB 2.0 Signal Quality Test Option for InfiniiVision 4000 and 6000 X-Series Oscilloscopes</i>	Data Sheet	5991-1762EN
<i>Serial Bus Options for InfiniiVision Series Oscilloscopes</i>	Data Sheet	5990-6677EN
<i>Fast Waveform Update Rates Enhance the Probability of Capturing Elusive Events</i>	Application Note	5989-7885EN
<i>Triggering on Infrequent Anomalies using InfiniiScan Zone Trigger</i>	Application Note	5991-1107EN
<i>Using Oscilloscope Segmented Memory for Serial Bus Applications</i>	Application Note	5990-5817EN



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