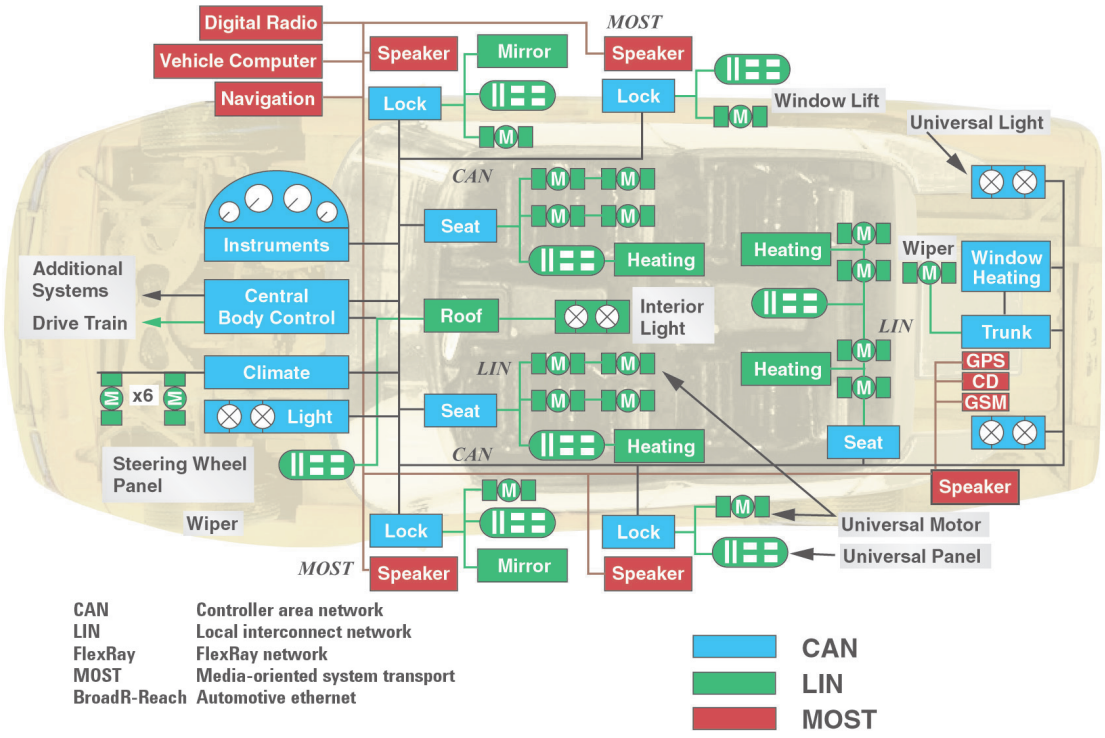
# Keysight Technologies
# Automotive Serial Bus Testing
## Using Keysight's InfiniiVision X-Series and Infiniium S-Series Oscilloscopes

Application Note




KEYSIGHT TECHNOLOGIES

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# Introduction

The primary reason engineers use oscilloscopes to debug and characterize automotive serial buses such as CAN, CAN FD, LIN, FlexRay, SENT, BroadR-Reach, and MOST, is because of an oscilloscope's inherent ability to characterize the analog quality of these signals. Performing analog characterization using an oscilloscope is often referred to as "physical layer" testing. Serial bus protocol analyzers are optimized for performing measurements at the "application layer". Instruments such as these are focused on providing trace flow of data at a higher abstraction level — but at the cost of providing little or no physical layer measurement capability.

This application note will show a few examples of characterizing the performance of various automotive serial buses. The examples provided use a Keysight Technologies, Inc. InfiniiVision X-Series and an Infiniium S-Series oscilloscope and illustrate the strength of each platform. Also included is a summary of recommended probing solutions, and how to select which oscilloscope platform may best suit your particular automotive debugging and analysis measurement needs.

# Decoding and Triggering on CAN, CAN FD, LIN, FlexRay, and SENT

Inherently an oscilloscope is designed to show the quality of analog signals. However in the case of these buses specifically, just seeing is often not enough. Many oscilloscopes today can be set up to trigger on specific events to bring into focus the details of how these buses communicate. Decoding and triggering on common automotive serial control buses such as CAN, CAN FD, LIN, FlexRay, and SENT is essential for identifying and monitoring the signal quality of specific frames/messages, as well as measuring the timing between frames. Figure 1(a) shows an example of capturing and decoding a LIN bus and a CAN bus simultaneously using a Keysight InfiniiVision 4000 X-Series oscilloscope. At the bottom of the scope's display are the decode traces that are time-correlated to each captured packet (Ch1/yellow trace = CAN bus, Ch2/green trace = LIN bus). The upper half of the scope's display shows the time-interleaved protocol decode lister/table. The time-interleaved lister display shown in the expanded view in Figure 1(b) is unique to Keysight InfiniiVision X-Series oscilloscopes. Since the lister shows each message received in time-sequence – whether from the CAN bus or the LIN bus – this makes it easier and more intuitive to perform gateway timing measurements between multi-bus transfers of data. Note that this could apply to any two buses, such as CAN1-to-CAN FD2.

Another unique capability of Keysight's InfiniiVision X-Series oscilloscope is hardware-based decoding. This means that fast waveform update rates can be maintained (up to 1,000,000 waveforms/sec), and decode update rates are virtually real-time. This enhances the scopes ability to capture random and infrequent communication errors such as error frames because the scope doesn't have to slow down to update the screen.


Figure 1(a). Decoding a LIN bus and CAN bus simultaneously using a Keysight InfiniiVision X-Series oscilloscope.

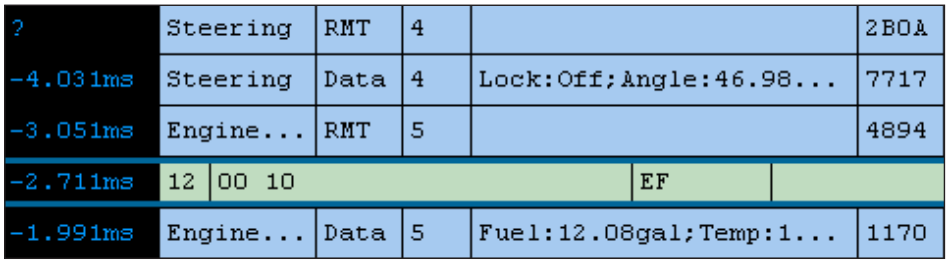



Figure 1(b). Expanded view for four lines of the protocol decode lister showing the time-sequence of CAN messages (blue lines) and LIN messages (green lines). Being able to see this level of detail of each message sent over the bus makes it much more intuitive to perform timing measurements between buses.

# Decoding and Triggering on CAN, CAN FD, LIN, FlexRay, and SENT (Continued)

Also available in Keysight's InfiniiVision 3000-T, 4000, and 6000 X-Series, as well as the Infiniium S-Series oscilloscopes, is symbolic-level decoding of the CAN bus. These scopes can also trigger on the symbolic message name and signal values or encoded states of those signals.

With the use of a .dbc file, without any special translation or PC software, more insight can be provided into the trace flow information that is normally exclusive to a protocol analyzer. This capability interprets the data into meaningful information. Symbolic-level decoding of the CAN bus is a standard capability of the CAN trigger and decode option for each of these oscilloscope series from Keysight.

Figure 2(a) shows an example of symbolically decoding a 500 kbps differential CAN bus using an Infiniium S-Series oscilloscope. In addition to displaying message and signal names along with numerical values with units, the InfiniiVision X-Series and Infiniium S-Series are the only scopes on the market that can also display the status of state-encoded signals in symbolic format. Figure 2(b) shows an expanded view of lines #8 though #10 of the protocol lister of Figure 2(a). "Armed", "Deployed", "Unlocked", and "Locked" are all examples of encoded states. The scope can interpret these encoded states because of the .dbc file that can be imported directly, ultimately saving the user in manual translation time.

In addition the Infiniium S-Series oscilloscopes can provide flexible ways to view the decoded information. You even have the ability to drill-down for a more detailed view of decoded data at the bit/field boundary level as shown in the lower pane of the main screen Figure 2(a), expanded in Figure 2(c).

To learn more about CAN symbolic level triggering and decode refer to the application notes listed under related literature at the end of this document.

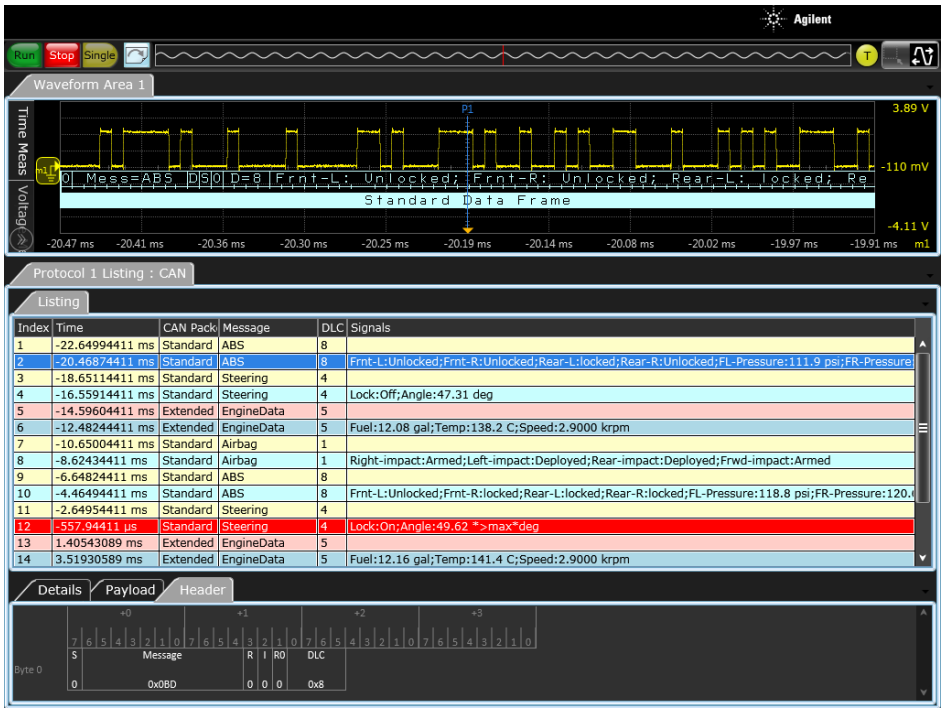



Figure 2(a). CAN symbolic decoding using a Keysight Infiniium S-Series oscilloscope.

| | | |
|---|---|---|
| Airbag | 1 | Right-impact:Armed;Left-impact:Deployed;Rear-impact:Deployed; |
| ABS | 8 | |
| ABS | 8 | Frnt-L:Unlocked;Frnt-R:locked;Rear-L:locked;Rear-R:locked;FL-Pr |

Figure 2(b). Message "Airbag" and message "ABS" include examples of state-encoded signals.

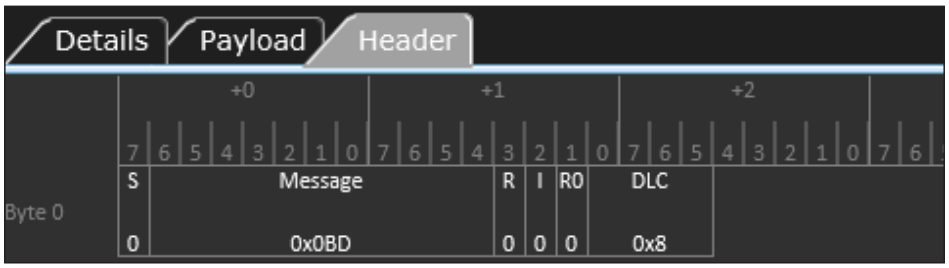



Figure 2(c). Drilling down to an even more detailed view of decoded data is shown here in bit/field boundary level decoding using a Keysight Infiniium S-Series oscilloscope.

# Capturing Long Time-spans of Automotive Serial Data

Sometimes it may be necessary to capture data from automotive serial buses over long and continuous time-spans, such as power-up sequences. Unfortunately, all scopes have limited amounts of acquisition memory, and that limits the maximum time-span and number of messages/ frames that can be captured and decoded. Keysight's Infiniium S-Series oscilloscopes come standard with 50 Mpts of acquisition memory, and can even be optioned-up to 800 Mpts. This is the deepest memory available today in any oscilloscope in this performance category which allows you to capture and view the longest continuous time-span of serial data possible.

But sometimes even 800 Mpts of acquisition memory may not be sufficient. To effectively use memory and extend the amount of time that can be captured selectively, segmented memory acquisition is available in the Infiniium S-Series oscilloscopes.

The InfiniiVision X-Series oscilloscopes come standard with 4 Mpts of acquisition memory; as well as the segmented memory acquisition mode. With segmented memory, the scope optimizes available acquisition memory by selectively capturing multiple and consecutive occurrences of specific messages based on the scope's trigger condition.

Figure 3 shows an example of capturing 1000 consecutive occurrences of just CAN messages that contain errors (CRC errors, stuffed bit errors, no acknowledge bit, and flagged error frames) over a 100 second time-span.

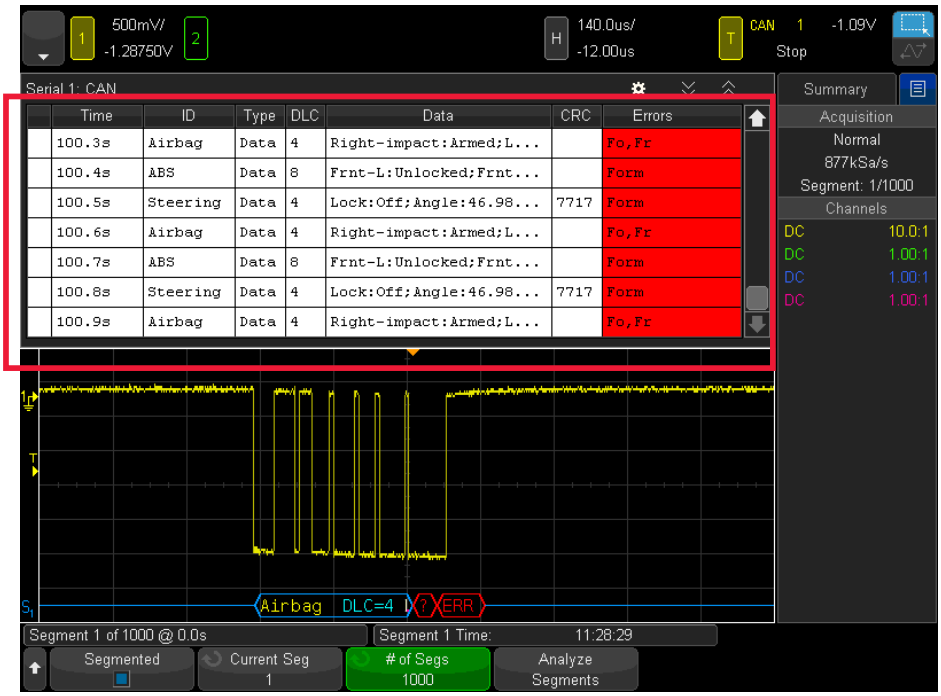



Figure 3. Using Segmented Memory to capture 1000 consecutive CAN bus errors over a 100 second time-span.

Also shown in this measurement example using segmented memory is the symbolic decode of all 1000 captured messages in the protocol lister display (upper half of scope's display). The InfiniiVision X-Series are the only oscilloscopes on the market today that can decode all segments – not just the selected segment.

To learn more about segmented memory for serial bus applications refer to the application note listed under related literature at the end of this document.

# Eye-diagram Mask Testing

Another test that is often used to characterize the physical layer of automotive serial buses is an eye-diagram mask test. An oscilloscope eye-diagram provides a composite measure of the overall quality of the physical layer in one simple measurement. Keysight oscilloscopes can perform eye-diagram pass/fail testing on the differential CAN bus (InfiniiVision X-Series only), the differential FlexRay bus, as well as the differential MOST50 and MOST150 buses (Infiniium S-Series only). Several different industry standard masks based on various test planes and baud rates for each of these buses can be download for no charge from the Keysight.com website.

Figure 4 shows an example of a “TP4” eye-diagram mask test at the input of a FlexRay receiver using an InfiniiVision X-Series oscilloscope. In this measurement example, we can see significant edge jitter, slow rising and falling edges, and a shifted bit that intersects the pass/fail mask causing mask test failures.

Figure 5 shows an example of a differential CAN bus eye-diagram mask test. The apparent jitter displayed in a CAN eye-diagram is dominated by network propagation delay from asynchronous nodes transmitting data from different physical locations in the network. The Keysight InfiniiVision X-Series are the only oscilloscopes in the industry that can perform CAN eye-diagram mask testing.

To learn more about eye diagram mask testing on automotive serial buses refer to the application notes listed under related literature at the end of this document.

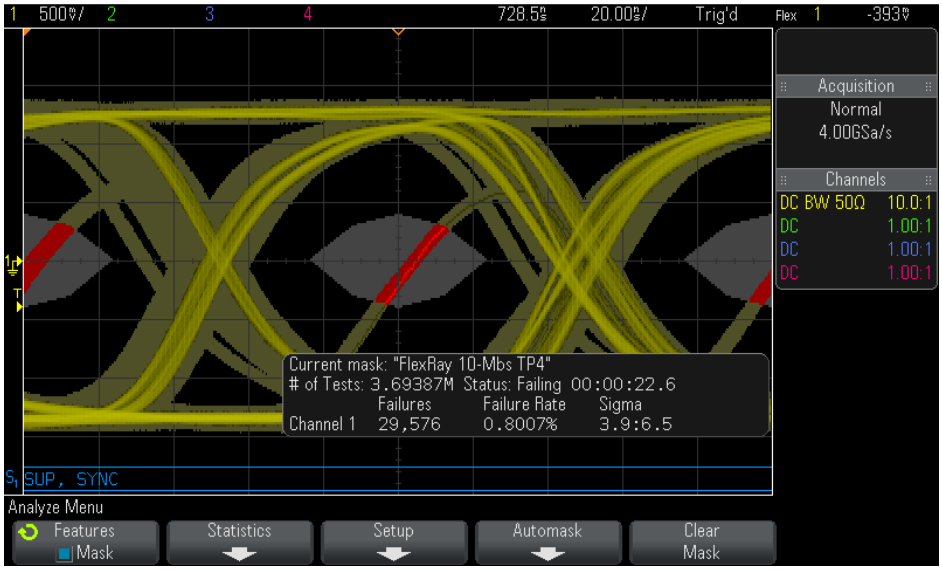



Figure 4. An eye-diagram mask test on a FlexRay bus reveals a shifted bit.

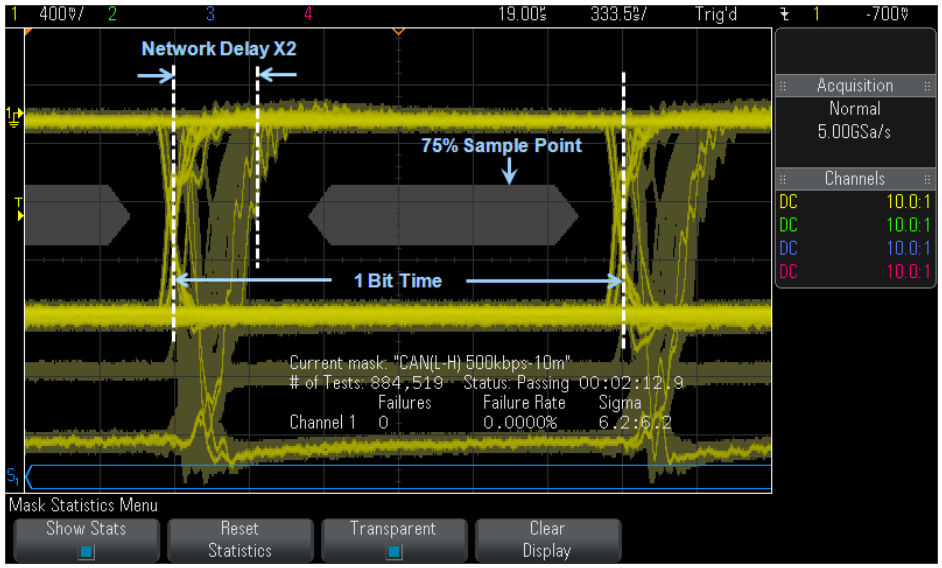



Figure 5. CAN eye-diagram mask test using a Keysight InfiniiVision X-Series oscilloscope.

# Physical Layer Compliance Testing

For some the newer automotive serial buses there are specific compliance tests that must be met. These tests are set up by a standards body and ensure that all components that utilize these buses does so in a way that will work together, thereby providing consistency between vendors.

Fully automated testing with comprehensive test reports of the FlexRay (InfiniiVision X-Series only), BroadR-Reach (Infiniium S-Series only), and MOST50/150 (Infiniium S-Series only) automotive serial buses based on industry standards/ specifications is available on Keysight oscilloscopes. Figure 6 shows an example a FlexRay summary test report, along with a detailed report of an isolated one's measurement using an InfiniiVision X-Series oscilloscope.

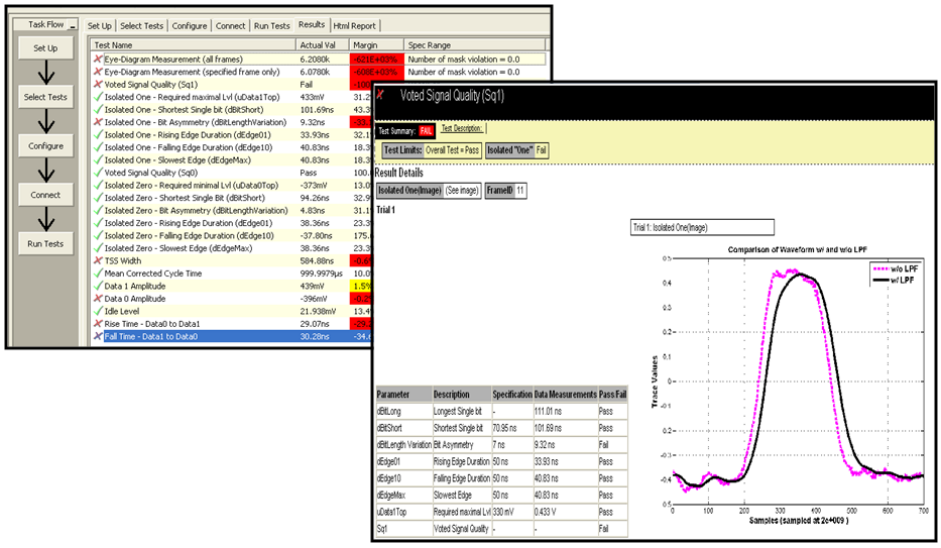



Figure 6. FlexRay physical layer compliance test using a Keysight InfiniiVision X-Series oscilloscope.

Figure 7 shows an example summary report of a test on an automotive MOST150 network using an Infiniium S-Series oscilloscope. Although not shown in the document, the Infiniium S-Series oscilloscope can also perform similar physical layer compliance tests on the BroadR-Reach serial bus.

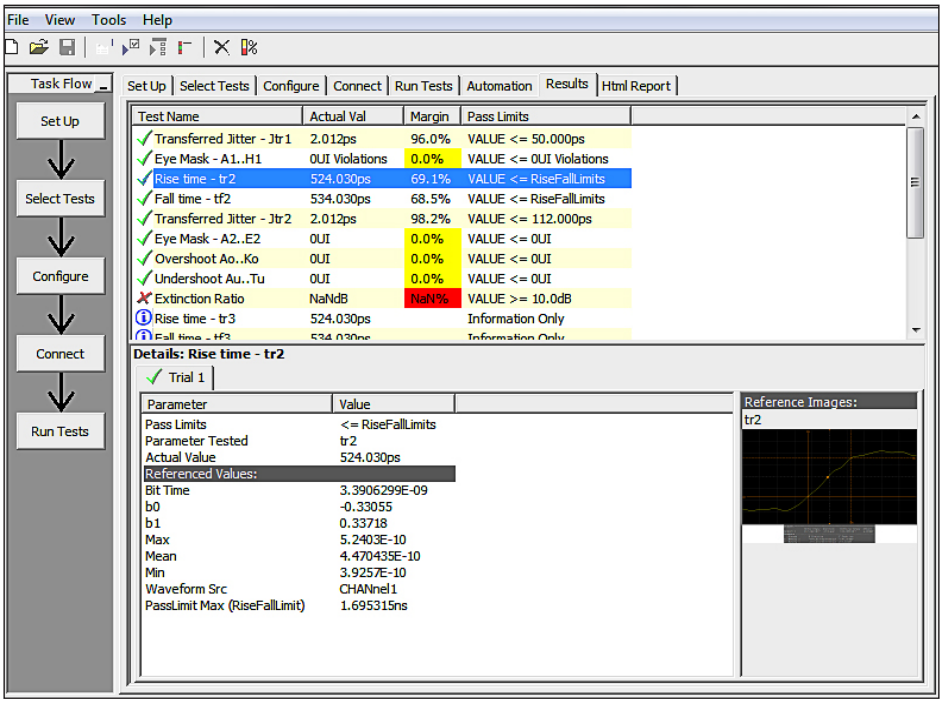



Figure 7. MOST150 physical layer compliance summary test report based a series of automated tests performed using a Keysight Infiniium S-Series oscilloscope.

# Probing Automotive Serial Buses

Let's now look at probing solutions. The LIN and SENT serial bus is a single-ended buses (signal -to-ground), and standard 10:1 passive probes can be used. However, most other serial buses in the automobile are differential, which means it is measuring between two different points and will need a differential probe to accurately capture it. For the differential CAN, CAN FD, and FlexRay buses, Keysight recommends using the 200-MHz bandwidth N2818A differential active probe shown in Figure 8. This probe is compatible with most models of the Keysight InfiniiVision X-Series oscilloscopes, and all models of the Infiniium S-Series oscilloscopes.

The N2818A differential active probe comes with Keysight's AutoProbe interface that powers up the active probe and automatically detects this probe's 10:1 probe attenuation factor and input termination impedance (50 Ω).

Also recommended if your CAN, CAN FD, and/or FlexRay system includes DB9-SubD type connectors is the CAN/FlexRay DB9 probe head (part number 0960-2926) shown in the inset of Figure 8. This probe head makes it quick and easy to connect to your CAN, CAN FD, and/or FlexRay differential buses.

For the higher bit rate BroadR-Reach and MOST50/150 measurement applications, Keysight recommends using the higher bandwidth N2750A InfiniiMode Series differential active probes (1.5 to 6 GHz bandwidth models) shown in Figure 9. The InfiniiMode Series probe allows you to view not only the differential signal, but you can also set it up to show each side of the differential bus relative to ground, as well as show the common mode of the bus – without ever moving probe connections.

The table on the right summarizes recommended probes for each automotive serial bus.

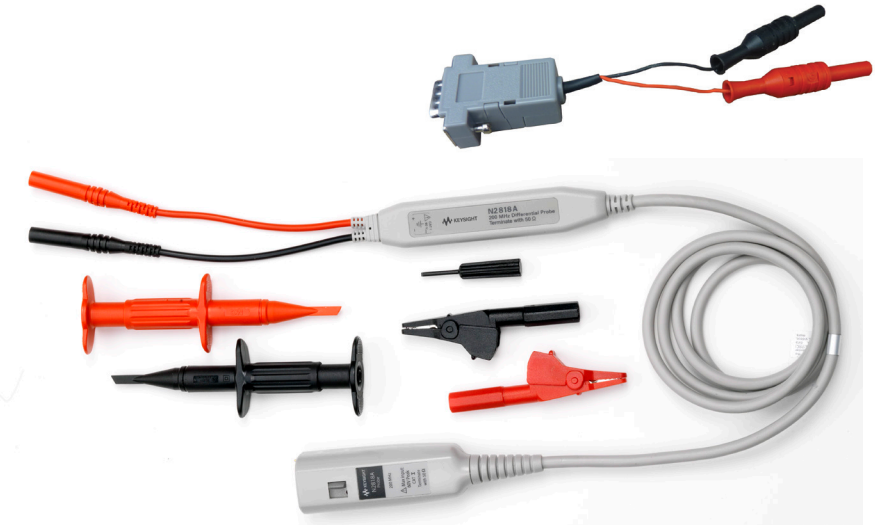


Figure 8. Keysight's N2818A 200-MHz differential active probe for CAN and FlexRay measurement applications. The optional DB9-SubD probe head makes it easy to connect to your differential bus.

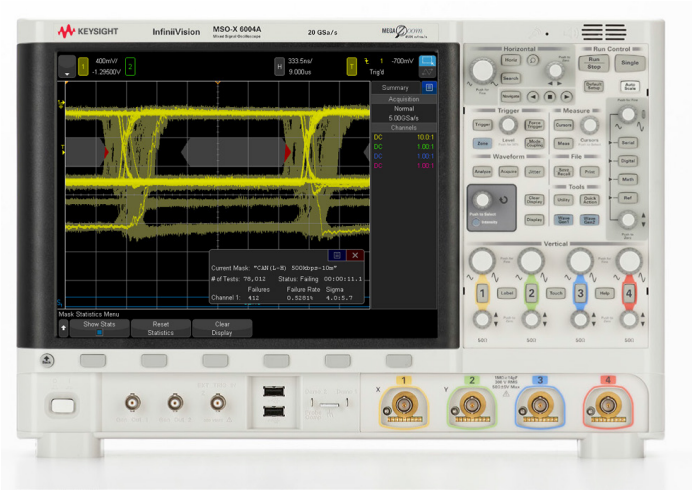
Figure 9. Keysight's N2750A InfiniiMode Series differential active probe for MOST50/150 and BroadR-Reach measurement applications.

| | Standard 10:1 single-ended passive probe | N2818A [1] 200-MHz differential active probe | N2750A 1.5-GHz differential active probe |
|---|---|---|---|
| LIN | √ | – | – |
| SENT | √ | – | – |
| CAN | – | √ | – |
| CAN FD | – | √ | – |
| FlexRay | – | √ | – |
| BroadR-Reach | – | – | √ |
| MOST50 | – | – | √ |
| MOST150 | – | – | √ |

1. The N2818A is not compatible with Keysight's InfiniiVision 2000 X-Series models. If using an InfiniiVision 2000 X-Series oscilloscope for differential CAN bus measurement applications, the 25-MHz bandwidth N2791A or the 200-MHz bandwidth N2792A differential active probe are recommended.

# Choosing the Right Oscilloscope Platform for Your Automotive Measurements

So which oscilloscope platform from Keysight best fits your automotive serial bus measurement needs; the InfiniiVision X-Series or the Infiniium S-Series? This depends on your oscilloscope performance requirements (bandwidth, sample rate, and memory depth), automotive measurement requirements (serial trigger and decode only or compliance testing), your use-model (debug or analysis), and your budget.




The Keysight InfiniiVision 6000 X-Series oscilloscope.

The Keysight InfiniiVision X-Series oscilloscopes come in various models with bandwidths ranging from 70 MHz up to 6 GHz bandwidth. This platform is based on a real-time operating system that has been optimized for debugging the physical layer of CAN, CAN FD, LIN, and FlexRay, and SENT serial bus designs with Keysight's fourth-generation MegaZoom technology. This Keysight-proprietary technology provides the fastest waveform update rates in the oscilloscope industry (up to 1,000,000 waveforms per second) so that you can capture infrequent transients – which are common and inherent in automotive electrical systems. The InfiniiVision X-Series oscilloscopes also begin at very low price-points.


The Keysight Infiniium S-Series oscilloscope.

The Keysight Infiniium S-Series oscilloscope provides up to 8 GHz bandwidth with sampling up to 20 GSa/s. These scopes also provide the deepest memory in the oscilloscope industry with 50 Mpts of standard memory and up to 800 Mpts of optional acquisition memory. This platform is based on a Windows operating system that has been optimized for advanced waveform analysis of automotive system designs. Besides supporting CAN, LIN, and FlexRay serial bus analysis and triggering, the Infiniium S-Series oscilloscopes also support compliance test options for the BroadR-Reach and MOST50/150 serial buses based on published industry physical layer standards.

The following table summarizes the features of Keysight's various automotive options in InfiniiVision X-Series and Infiniium S-Series oscilloscopes:

| | InfiniiVision 1000 X-Series | InfiniiVision 2000 X-Series | InfiniiVision 3000T X-Series | InfiniiVision 4000 X-Series | InfiniiVision 6000 X-Series | Infiniium S-Series |
|---|---|---|---|---|---|---|
| **Oscilloscope specifications** | | | | | | |
| Bandwidth | 50 to 100 MHz | 70 to 200 MHz | 100 MHz to 1 GHz | 200 MHz to 1.5 GHz | 1 to 6 GHz | 500 MHz to 8 GHz |
| Sample rate (max) | 2 GSa/s | 2 GSa/s | 4 GSa/s, 5 GSa/s | 5 GSa/s | 20 GSa/s | 20 GSa/s |
| Memory (max) | 1 Mpts | 1 Mpts | 4 Mpts | 4 Mpts | 4 Mpts | 800 Mpts |
| ADC resolution | 8 bits | 8 bits | 8 bits | 8 bits | 8 bits | 10 bits |
| Analog channels | 2 | 2 or 4 | 2 or 4 | 2 or 4 | 2 or 4 | 4 |
| Digital channels | – | 8-ch MSO | 16-ch MSO | 16-ch MSO | 16-ch MSO | 16-ch MSO |
| Update rate (max) | 50,000/sec | 50,000/sec | 1,000,000/sec | 1,000,000/sec | 450,000/sec | 1,000/sec |
| **Automotive serial bus decode and trigger** [1] | | | | | | |
| LIN decode and trigger | √ | √ | √ | √ | √ | √ |
| SENT decode and trigger | – | – | √ | √ | √ | – |
| CAN decode and trigger | √ | √ | √ | √ | √ | √ |
| CAN FD decode and trigger | – | – | √ | √ | – | – |
| CAN symbolic (.dbc) decode and trigger | – | – | √ | √ | √ | √ |
| FlexRay decode | – | – | √ | √ | √ | √ |
| FlexRay trigger | – | – | √ | √ | √ | Software-based search trigger only |
| **Special decode features** | | | | | | |
| Hardware-based decoding | √ | √ | √ | √ | √ | – |
| Segmented mem with decode | Selected segment only | All segments in lister | All segments in lister | All segments in lister | All segments in lister | Selected segment only |
| Multi-bus decode | 1 bus | 1 bus | 2 buses | 2 buses | 2 buses | 4 buses |
| Dual-bus with interleaved lister | – | – | √ | √ | √ | – |
| Frame/error counter with bus load (CAN) | √ | √ | √ | √ | √ | – |
| Field/bit-level boundary markers | – | – | – | – | – | √ |
| **Eye-diagram mask testing** | | | | | | |
| CAN | √ | √ | √ | √ | √ | – |
| CAN FD | – | – | √ | √ | – | – |
| FlexRay | – | – | √ | √ | √ | √ |
| MOST50/150 | – | – | – | – | – | √ |
| **Automated compliance testing** | | | | | | |
| FlexRay (PC-based) | – | – | √ | √ | √ | – |
| MOST50 | – | – | – | – | – | √ |
| MOST150 | – | – | – | – | – | √ |
| BroadR-reach | – | – | – | – | – | √ |

1. In addition to supporting the most common automotive serial buses listed in this table, these oscilloscopes also support a broad range of other general-purpose serial buses such as $I^2C$, SPI, RS-233, USB, etc.

# Related Literature

| Publication title | Publication number |
|---|---|
| **Keysight InfiniiVision X-Series literature** | |
| *InfiniiVision 1000 X-Series Oscilloscopes* - Data Sheet | 5992-1965EN |
| *InfiniiVision 2000 X-Series Oscilloscopes* - Data Sheet | 5990-6618EN |
| *InfiniiVision 3000 X-Series Oscilloscopes* - Data Sheet | 5990-6619EN |
| *InfiniiVision 4000 X-Series Oscilloscopes* - Data Sheet | 5991-1103EN |
| *InfiniiVision 6000 X-Series Oscilloscopes* - Data Sheet | 5991-4087EN |
| *Serial Bus Options for InfiniiVision X-Series Oscilloscopes* - Data Sheet | 5990-6677EN |
| *Debug Automotive Designs Faster with CAN-dbc Symbolic Trigger and Decode* - Application Note | 5991-2847EN |
| *Characterizing CAN Bus Arbitration Using InfiniiVision 4000/6000 X-Series Oscilloscope* - Application Note | 5991-4166EN |
| *Oscilloscope Measurement Tools to Help Debug Automotive Serial Buses Faster* - Application Note | 5991-0512EN |
| *CAN Eye-Diagram Mask Testing* - Application Note | 5991-0484EN |
| *FlexRay Physical Layer Eye-diagram Mask Testing* - Application Note | 5990-4923EN |
| *Using Oscilloscope Segmented Memory for Serial Bus Applications* - Application Note | 5990-5817EN |
| **Keysight Infiniium S-Series literature** | |
| *Infiniium S-Series High-Definition Oscilloscopes* - Data Sheet | 5991-3904EN |
| *CAN, LIN and FlexRay Protocol Triggering and Decode for Infiniium 9000 and S-Series Oscilloscopes* - Data Sheet | 5990-5077EN |
| *MOST Compliance Application for Infiniium Oscilloscopes* - Data Sheet | 5991-2048EN |
| *N6467A BroadR-Reach Automotive Ethernet Electrical Compliance Application* - Data Sheet | 5991-1965EN |
| *Debug Automotive Designs Faster with CAN-dbc Symbolic Trigger and Decode For Keysight Infiniium Oscilloscopes* - Application Note | 5991-3293EN |

To download these documents, insert the publication number in the URL: http://literature.cdn.keysight.com/litweb/pdf/xxxx-xxxx.pdf

# Ordering Information

| InfiniiVision X-Series Oscilloscopes | | | | | |
|---|---|---|---|---|---|
| | 1000 X-Series | 2000 X-Series | 3000T X-Series | 4000 X-Series | 6000 X-Series |
| CAN/LIN trigger and decode | DSOX1AUTO | DSOX2AUTO | – | – | – |
| CAN/CAN FD/ CAN-dbc/LIN trigger and decode | – | – | – | DSOX4AUTO | – |
| CAN/CAN-dbc/LIN trigger and decode | – | – | DSOXT3AUTO | – | DSOX6AUTO |
| SENT trigger and decode | – | – | DSOX3SENSOR | DSOX4SENSOR | DSOX6SENSOR |
| FlexRay trigger and decode | – | – | DSOX3FLEX | DSOX4FLEX | DSOX6FLEX |
| Mask test [1] | Standard [2] | DSOX2MASK | DSOX3MASK | DSOX4MASK | DSOX6MASK |
| Segmented memory | Standard [2] | DSOX2SGM | DSOX3SGM | Standard | Standard |

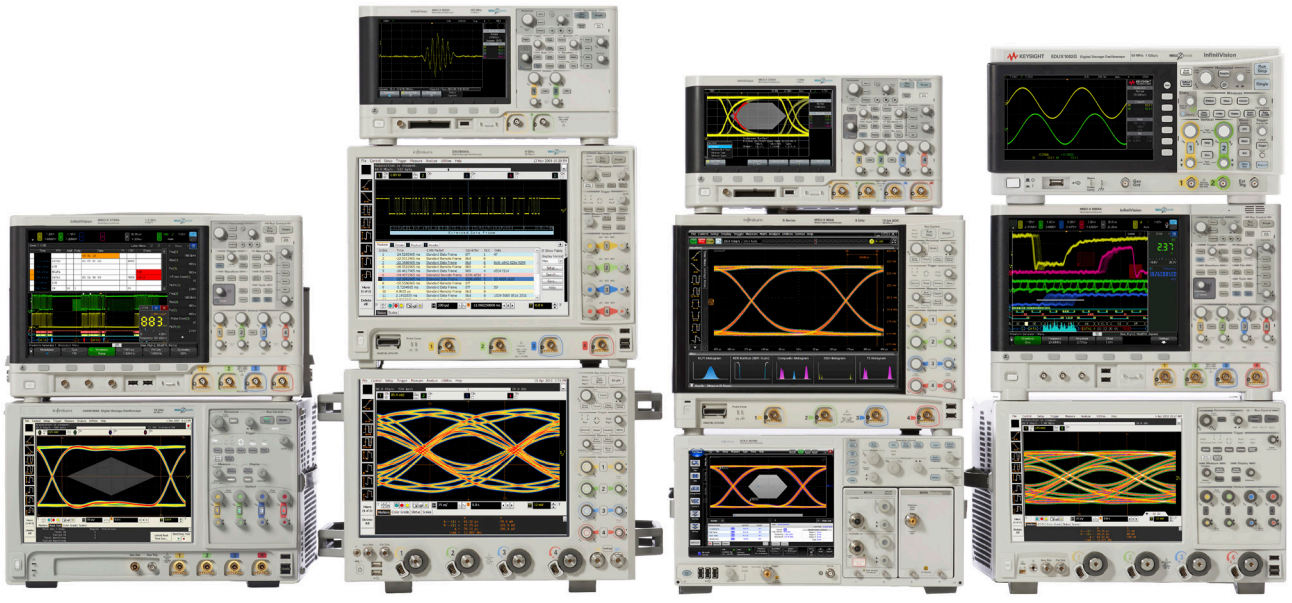
1. Mask test option and specific serial bus option(s) required to support CAN and/or FlexRay eye-diagram mask testing. Mask files supporting various baud rates and test planes can be downloaded at no charge.
2. DSO models only.

| Infiniium S-Series Oscilloscopes | |
|---|---|
| CAN/CAN-dbc/LIN/FlexRay trigger and decode | N8803A-1FP |
| MOST50/150 physical layer compliance application | N6466A-1FP |
| BroadR-Reach physical layer compliance application | N6467A-1FP |
| Mask test | Standard |
| Segmented memory | Standard |

For additional options available in these oscilloscopes, refer to the data sheet for specific models listed in the Related Literature section of this document.

## Product website

For the most up-to-date and complete application and product information, please visit our product website at:
**www.keysight.com/find/scopes-auto**



www.axiestandard.org

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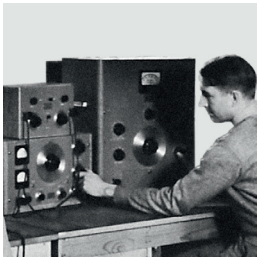

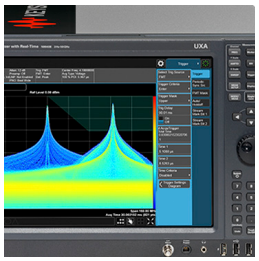

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