WHITE PAPER

Automotive Serial Bus Testing Using Oscilloscopes

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.

Learn how to use oscilloscopes to characterize the performance of your automotive buses including CAN, CAN FD, LIN, FlexRay, and SENT. This white paper will show you how to decode, trigger, and symbolically decode your buses. It also includes examples of identifying errors and signal quality issues in your automotive designs.

KEYSIGHT TECHNOLOGIES

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

Oscilloscopes show the quality of analog signals. Many oscilloscopes can be set up to trigger on specific events to bring into focus the details of how 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.

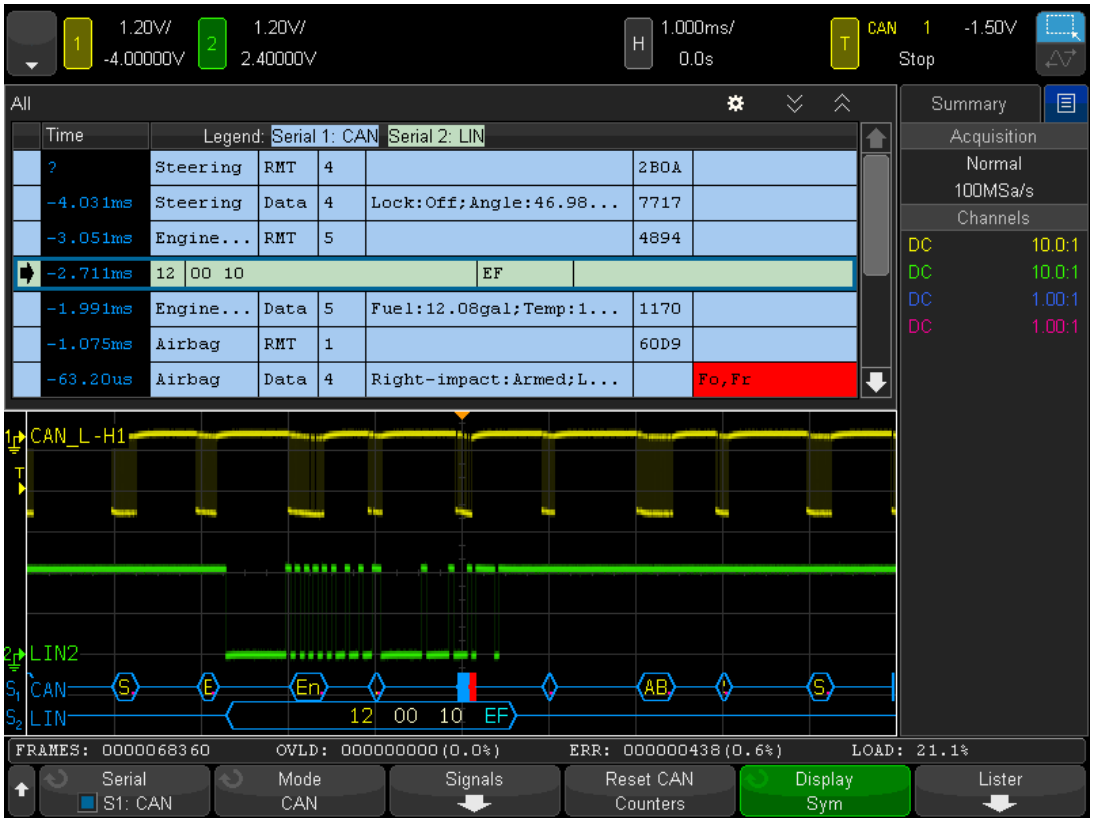


Figure 1(a): Decoding a LIN bus and CAN bus simultaneously using a Keysight InfiniiVision X-Series oscilloscope

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. 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.

The time-interleaved lister display shown in the expanded view in Figure 1(b) is unique to Keysight InfiniiVision X-Series oscilloscopes.

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.

For more intuitive measurements, some scopes can decode and trigger on the symbolic message name and signal values, or the encoded states of those signals. Use a scope with this capability to remove the tedious task of manually translating the data.

?	Steering	RMT	4		2B0A
-4.031ms	Steering	Data	4	Lock:Off;Angle:46.98...	7717
-3.051ms	Engine...	RMT	5		4894
-2.711ms	12	00 10		EF	
-1.991ms	Engine...	Data	5	Fuel:12.08gal;Temp:1...	1170

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

To do this, load your .dbc file into the oscilloscope. Your .dbc file contains the definition of your CAN bus messages. The scope uses the .dbc file to translate the raw, hex value represented data to physical, readable messages. This gives you insight into the trace flow information of your signal, which is normally only achievable with a protocol analyzer.

Figure 2 shows a close-up view of a protocol lister. “Armed”, “Deployed”, “Unlocked”, and “Locked” are all examples of encoded states.

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: Message “Airbag” and message “ABS” include examples of state-encoded signals

Symbolic-level decoding of the CAN bus is a standard capability of the CAN trigger and decode option on Keysight oscilloscopes.

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.

Use memory effectively and extend the amount of time that can be captured with segmented memory acquisition.

Segmented memory 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 CAN messages that contain errors (CRC errors, stuffed bit errors, no acknowledge bit, and flagged error frames) over a 100 second time-span.

To learn more about segmented memory for serial bus applications read the application note, Using Oscilloscope Segmented Memory for Serial Bus Applications.

The InfiniiVision X-Series oscilloscopes come standard with 4 Mpts of acquisition memory; as well as the segmented memory acquisition mode.

The InfiniiVision X-Series are the only oscilloscopes on the market today that can decode all segments — not just the selected segment.

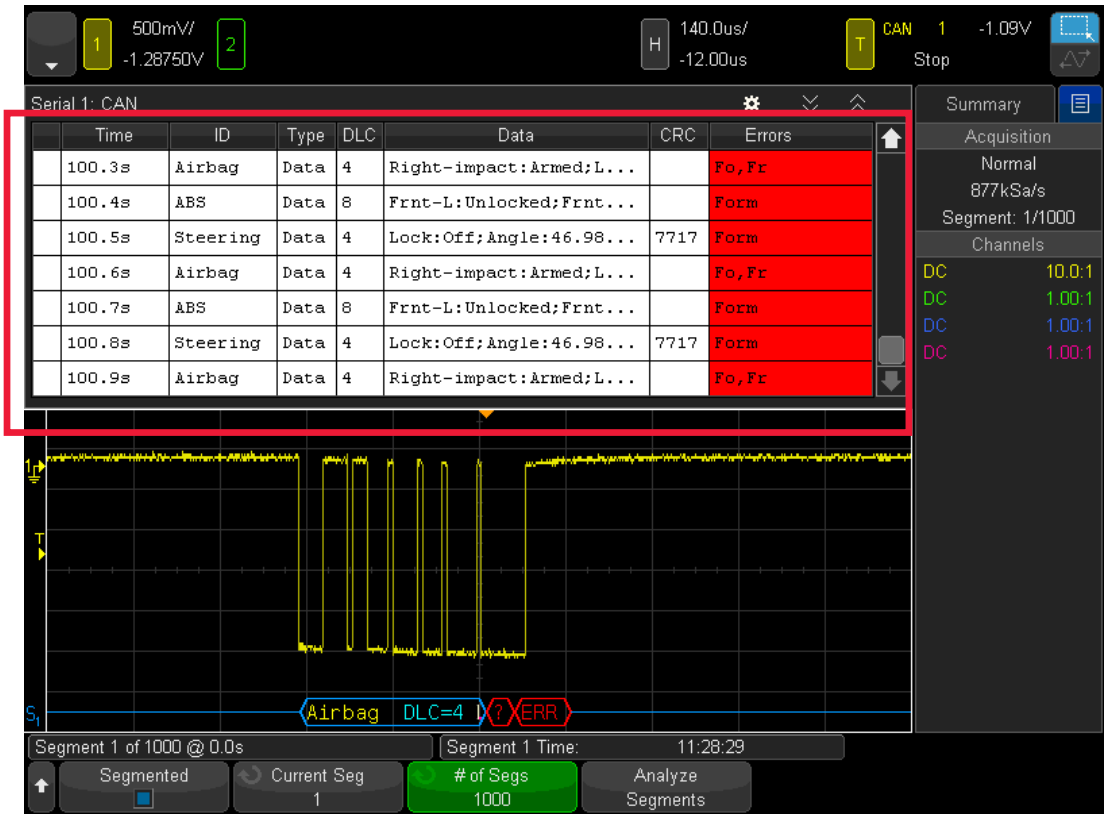


Figure 3: Using segmented memory to capture 1000 consecutive CAN bus errors over a 100 second time-span

Eye-Diagram Mask Testing

Eye-diagram mask tests are a test often used to characterize the physical layer of automotive serial buses. An oscilloscope eye-diagram provides a composite measure of the overall quality of the physical layer in one simple measurement. Keysight InfiniiVision oscilloscopes can perform eye-diagram pass/fail testing on differential CAN and FlexRay buses. You can download several different industry standard CAN and FlexRay masks from Keysight at no charge.

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 you can see significant edge jitter, slow rising and falling edges, and a shifted bit that intersects the pass/fail mask causing mask test failures.

The Keysight InfiniiVision X-Series are the only oscilloscopes in the industry that can perform CAN eye-diagram mask testing.

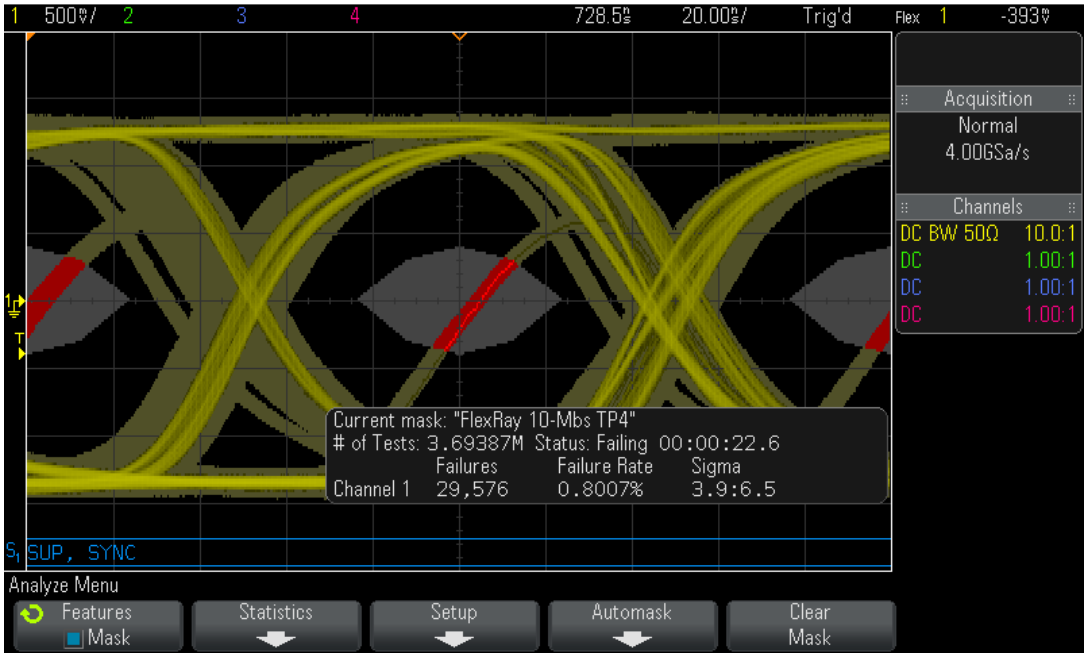


Figure 4: An eye-diagram mask test on a FlexRay bus reveals a shifted bit

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.

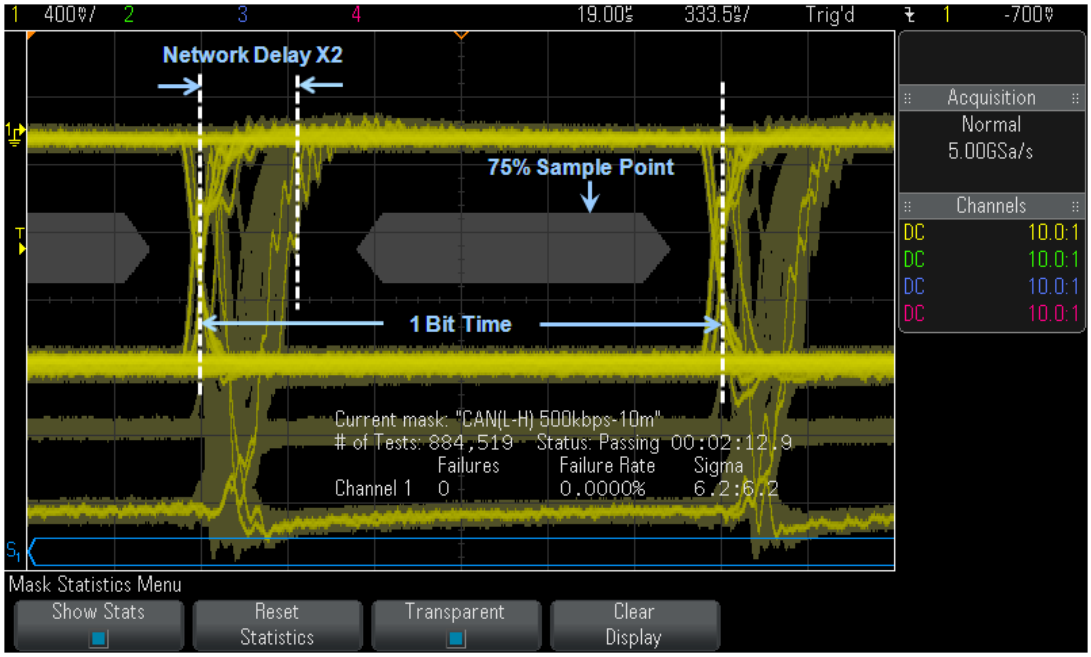


Figure 5: CAN eye-diagram mask test using a Keysight InfiniiVision X-Series oscilloscope

To learn more about eye diagram mask testing on automotive serial buses refer to the application notes, CAN Eye-Diagram Mask Testing and FlexRay Physical Layer Eye-Diagram Mask Testing.

Probing Automotive Serial Buses

All of these tests are pointless if you don't have a clean connection to your device. LIN and SENT are single-ended buses (signal-to-ground). Use a standard 10:1 passive probes to connect to these signals. Most other serial buses in the automobile like CAN, CAN FD, and FlexRay, are differential, which means you need to measure between two different points. To do this, you need a differential probe to accurately capture it.

	Standard 10:1 single-ended passive probe	N2818A 200-MHz differential active probe
LIN	√	–
SENT	√	–
CAN	–	√
CAN FD	–	√
FlexRay	–	√

For the differential CAN, CAN FD, and FlexRay buses, Keysight recommends using the 200-MHz bandwidth N2818A differential active probe.

The oscilloscope automatically detects this probe's 10:1 probe attenuation factor and input termination impedance (50 Ω).

The CAN/FlexRay DB9 probe head makes it quick and easy to connect to your CAN, CAN FD, and/or FlexRay differential buses.

Choosing the Right Oscilloscope Platform for Your Automotive Measurements

So which oscilloscope platform best fits your automotive serial bus measurement needs? This depends on your oscilloscope performance requirements (bandwidth, sample rate, memory, segmented memory, and speed of test), automotive measurement requirements, and your budget.

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, FlexRay, and SENT serial bus designs. InfiniiVision X-Series 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. They also provide hardware based decoding which make testing faster and more accurate than the software-based decoding you will find from other oscilloscope vendors. The InfiniiVision X-Series oscilloscopes also begin at very low price-points.

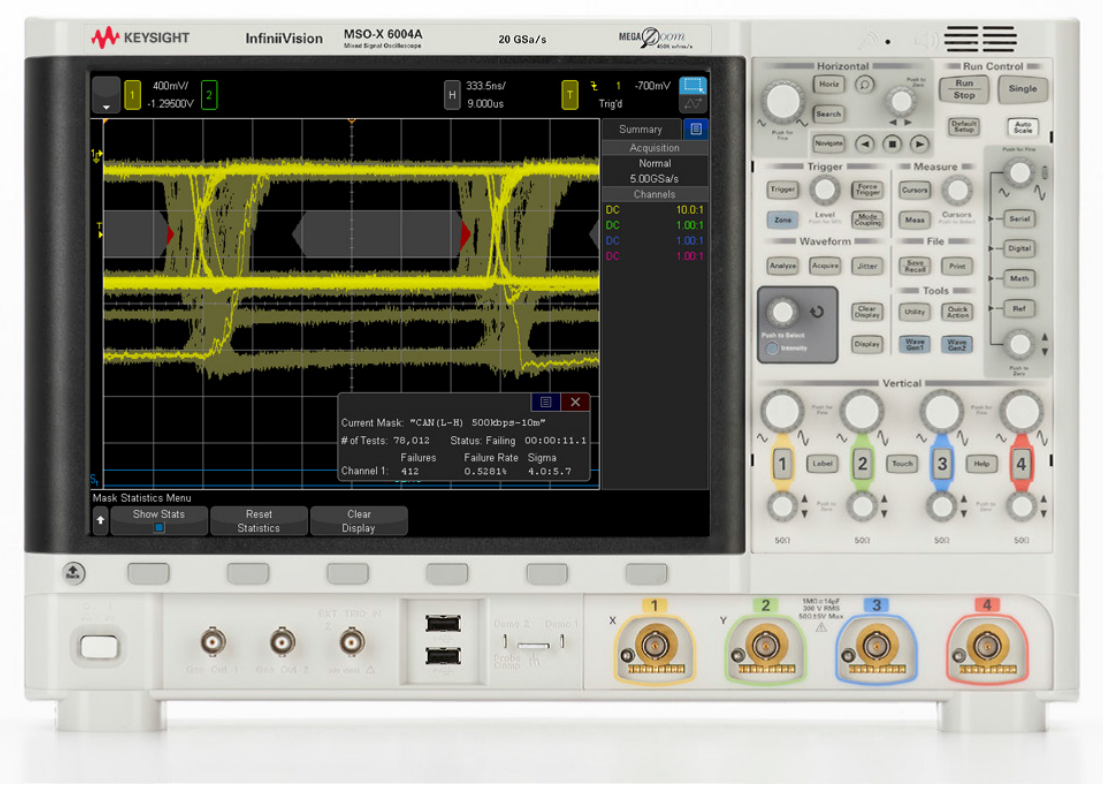


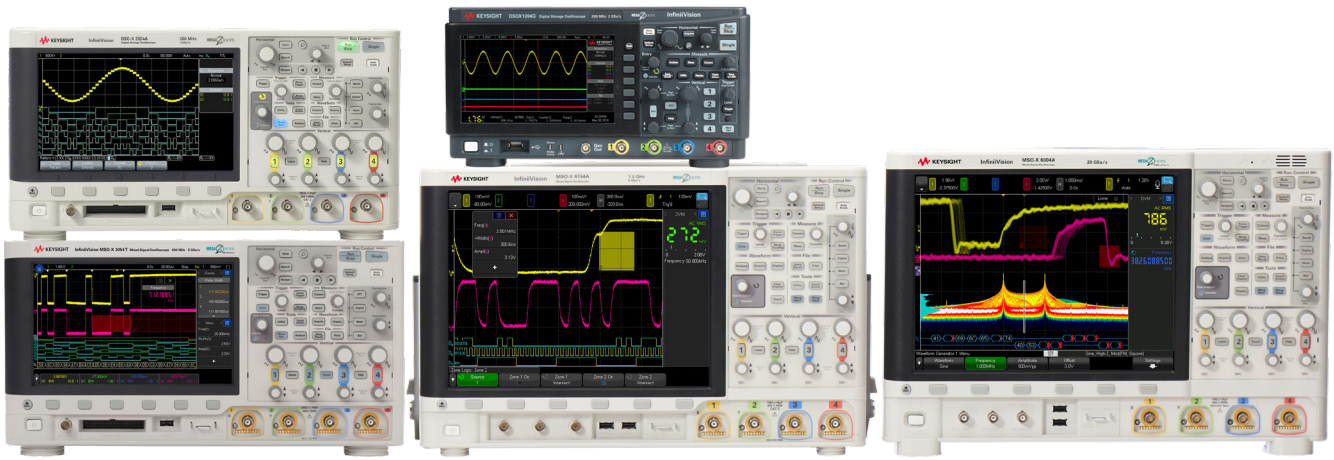
Figure 7: Mask limit test running on the Keysight InfiniiVision 6000 X-Series oscilloscope

The following table summarizes the specific measurement capabilities that are enabled on each InfiniiVision oscilloscope with the automotive application bundle.

Table 1. Automotive Software Packages InfiniiVision Oscilloscopes

InfiniiVision series	2000A	3000A	3000T	4000A	6000A	P9240	M9240
Automotive package model number	D2000AUTA	D3000AUTA	D3000AUTA	D4000AUTA	D6000AUTA	P9240AUTB	M9240AUTB
Serial trigger and decode							
CAN	√	√	√	√	√	√	√
CAN FD [1]			√	√	√	√	√
LIN [2]	√	√	√	√	√	√	√
FlexRay		√	√	√	√		
SENT			√	√	√	√	√
PSI5 (User-definable Manchester)			√	√	√	√	√
User-definable NRZ			√	√	√	√	√
CXPI			√	√	√	√	√
Advanced analysis							
Mask test [3]	√	√	√	√	√	√	√
Frequency response analysis			√	√	√	√	√
Advanced math	Std	√	Std	Std	Std	Std	Std

1. Symbolic decoding supported by importing a .dbc file, except on the 2000A and 3000A Series.
2. Symbolic decoding supported by importing a .ldf file, except on the 2000A and 3000A Series.
3. CAN, CAN FD, FlexRay, and SENT mask files available for download at no additional charge.

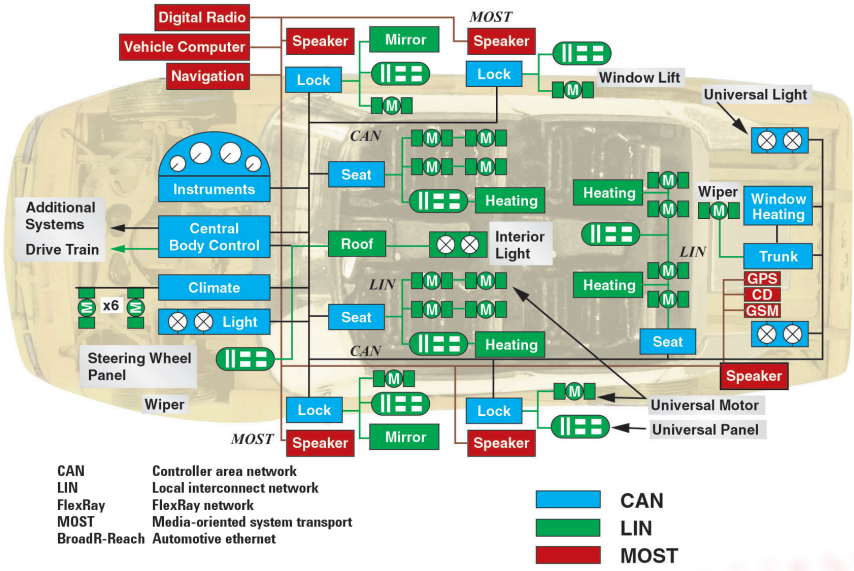


Learn More

- *InfiniiVision 3000T X-Series Oscilloscopes* - Data Sheet
- *InfiniiVision 4000 X-Series Oscilloscopes* - Data Sheet
- *InfiniiVision 6000 X-Series Oscilloscopes* - Data Sheet
- *Automotive Software Package for InfiniiVision X-Series Oscilloscopes* - Data Sheet
- *Characterizing CAN Bus Arbitration Using InfiniiVision 4000/6000 X-Series Oscilloscope* - Application Note
- *Oscilloscope Measurement Tools to Help Debug Automotive Serial Buses Faster* - Application Note

Product Website

For more automotive application and product information, please visit our product website at: www.keysight.com/find/scopes-auto



Learn more at: www.keysight.com

For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus

KEYSIGHT TECHNOLOGIES