APPLICATION NOTE

Using an Oscilloscope for Automotive Serial Bus Testing

Introduction

Engineers primarily use oscilloscopes to debug and characterize various automotive serial buses. These include the controller area network (CAN), CAN FD, CAN XL, local interconnect network (LIN), FlexRay, single-edge nibble transmission (SENT), and automotive Ethernet. An oscilloscope inherently characterizes the analog quality of these signals.

Performing analog characterization using an oscilloscope is often called **physical layer** testing. Serial bus protocol analyzers provide optimal measurement performance at the **application layer**. These instruments provide a trace flow of data at a higher abstract level.

This application note explains how to decode, trigger, and symbolically decode your buses. It also includes use-case examples for identifying errors and signal quality issues in your automotive designs.

Decoding and Triggering on Specific Events

Oscilloscopes display the quality of analog signals. Configuring an oscilloscope to trigger on specific events will bring into focus the details of how buses communicate. Decoding and triggering on common automotive serial control buses is essential for identifying and monitoring the signal quality of specific frames / messages and measuring the timing between frames. Figure 1(a) is 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 lower half of the oscilloscope's display are the decode traces that are time-correlated to each captured packet — Ch1 / yellow trace is the CAN bus, and Ch2 / green trace is the LIN bus. The upper half of the oscilloscope's display shows the time-interleaved protocol decode lister / table. The lister shows each message received in the specific time sequence — whether from the CAN bus or the LIN bus. This display makes it easier and more intuitive to perform gateway timing measurements between multi-bus data transfers. Note that this could apply to any two buses, such as CAN1 to CAN FD2.

For more intuitive measurements, some oscilloscopes can decode and trigger on the symbolic message name, signal values, or the encoded states of those signals. Use an oscilloscope with this capability to remove the 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

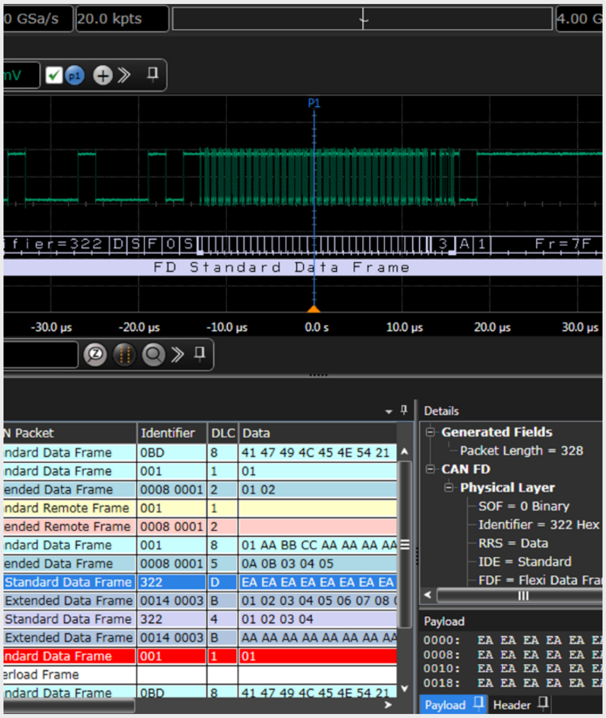
Figure 1(b). An example of the expanded view for four lines of the protocol decode lister displaying the time sequence of CAN messages (blue lines) and the LIN message (green line). Visibility to this level of detail of each message sent over the bus significantly enhances the intuitiveness of performing timing measurements between buses.

You need to load your .dbc file into the oscilloscope to accomplish this task. The .dbc file contains the definition of your CAN bus messages. The oscilloscope uses the .dbc file to translate the raw, hex value-represented data to physical, readable messages. This information provides visibility into the trace flow information of your signal, which is normally only achievable with a protocol analyzer. Figure 2 illustrates a close-up view of a protocol lister. Examples of encoded signal states are **Armed**, **Deployed**, **Unlocked**, and **Locked**.

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. Messages Airbag and ABS include examples of state-encoded signals

Keysight oscilloscope protocol trigger and decode packages make debugging and testing digital designs easy using a rich set of integrated protocol-level triggers specific to each serial bus. When you select serial triggering, the application enables special real-time triggering hardware inside the oscilloscope.



Test faster with the Keysight Infiniium MXR B-Series oscilloscope

- Trigger automatically and decode over 50 differential serial protocols, including 10BASE-T1S, 100BASE-T1 and 1000BASE-T1 protocols.
- Automate compliance measurements for automotive Ethernet Tx test from 10 Mbps to 5 Gbps.

Keysight Infiniium MXR B-Series oscilloscope

Capturing Long Time Spans of Automotive Serial Data

Sometimes, it is necessary to capture data from automotive serial buses over long and continuous time spans, such as in power-up sequences. Unfortunately, oscilloscopes have limited amounts of acquisition memory, and that limits the maximum timespan and number of messages / frames that the oscilloscope can capture and decode. 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 oscilloscope's trigger condition. Figure 3 is an example of capturing 1,000 consecutive occurrences of CAN messages that contain errors such as cyclic redundancy check errors, stuffed bit errors, no acknowledge bit, and flagged error frames over a 100-second time span.

Learn more about segmented memory for serial bus applications: Using Oscilloscope Segmented Memory for Serial Bus Applications – Application Note.

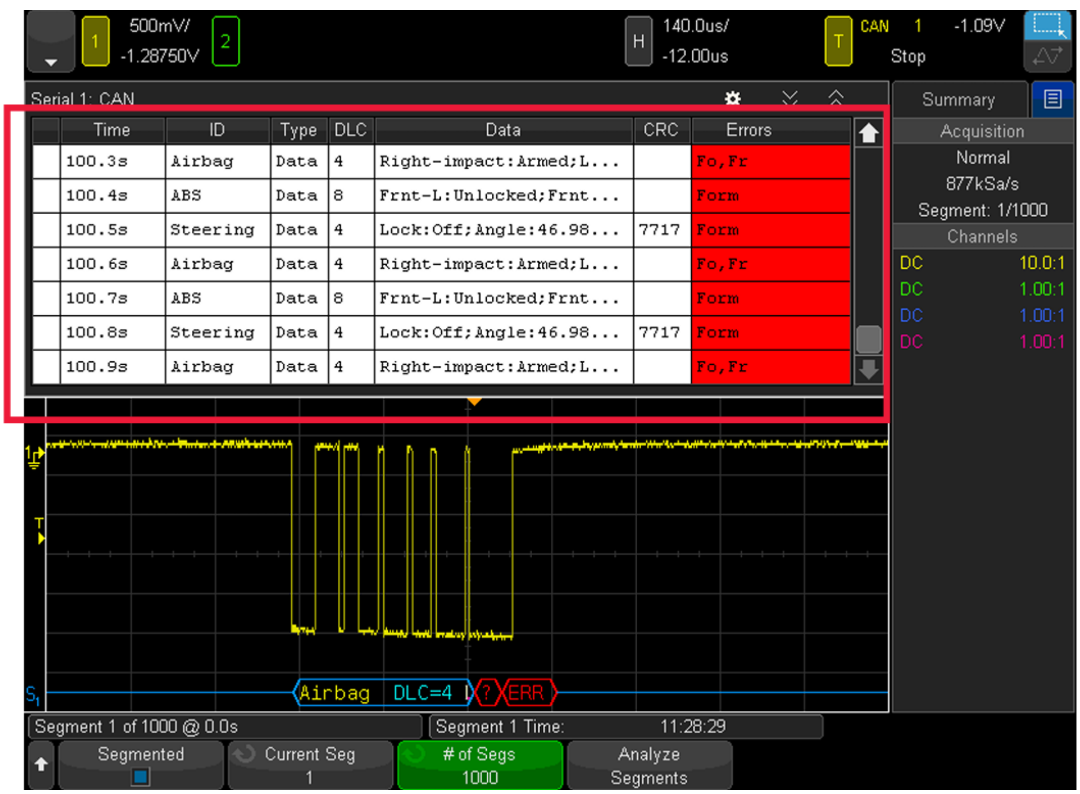


Figure 3. Example of using segmented memory to capture 1,000 consecutive CAN bus errors over a 100-second timespan

Using an Eye Diagram for Mask Testing

An eye diagram mask test characterizes 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.

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

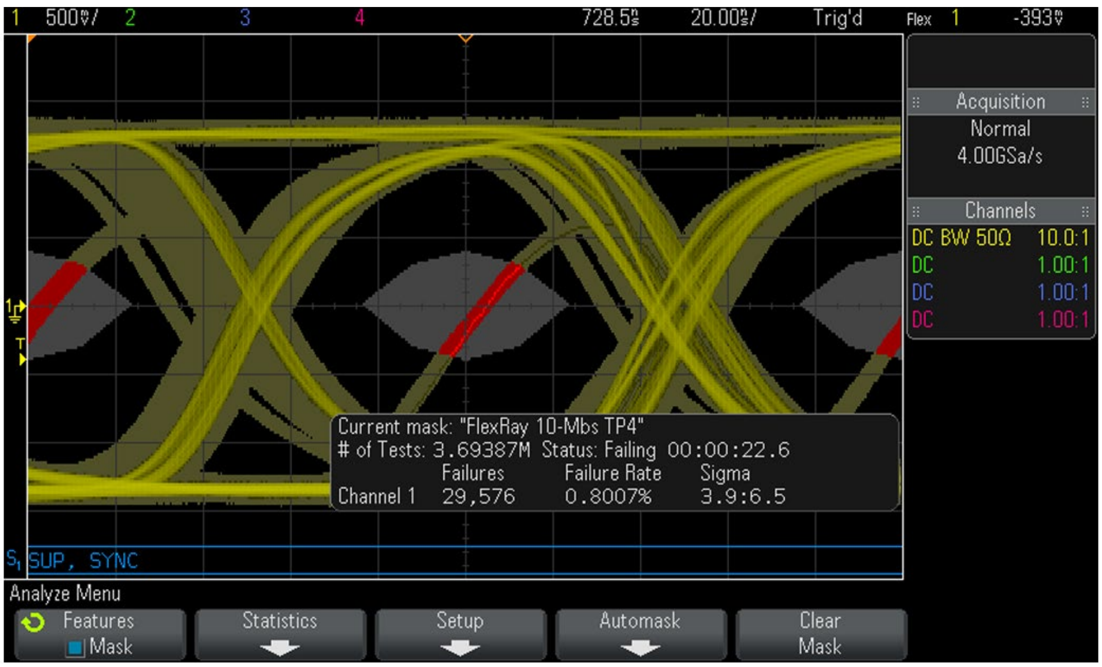


Figure 4. An eye diagram mask test on a FlexRay bus reveals a shifted bit

Figure 5 shows a differential CAN bus eye diagram mask test. The network propagation delay dominates the apparent jitter displayed in a CAN eye diagram due to asynchronous nodes transmitting data from different network physical locations.

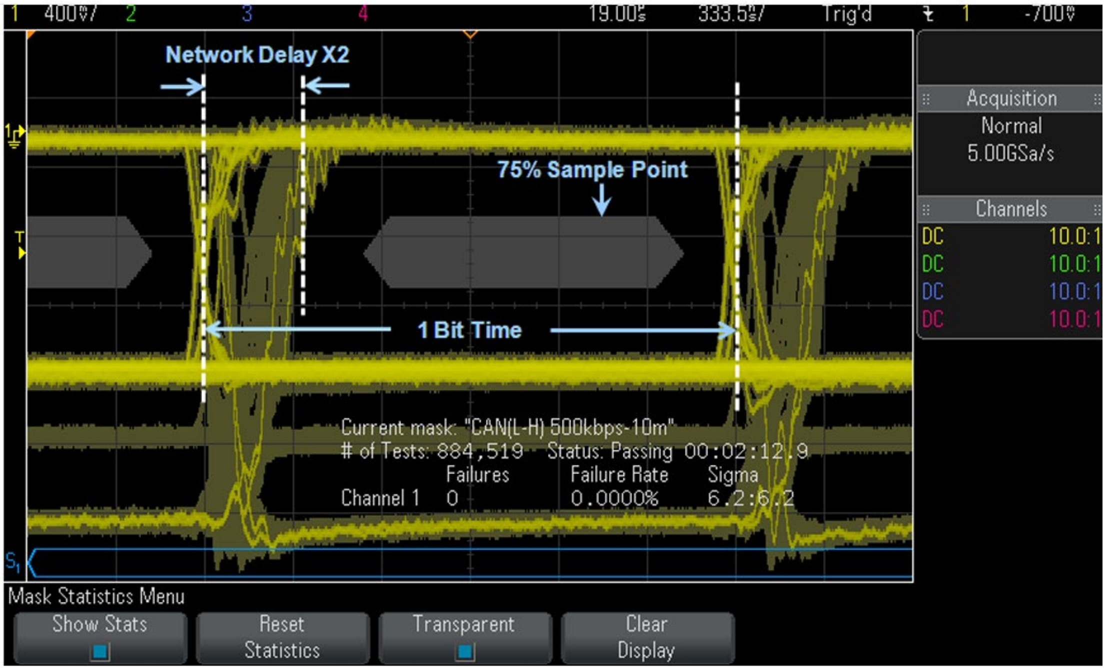


Figure 5. CAN eye diagram mask test using an InfiniiVision X-Series oscilloscope

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

Probing Automotive Serial Buses

Having a clean connection to your device is important before testing. LIN and SENT represent single-ended signal-to-ground buses. Use standard 10:1 high-impedance passive probes to connect to these signals. Most other serial buses in the automobile, like CAN, CAN FD, CAN XL, FlexRay, and automotive Ethernet, are differential, which means you must measure between two points. Table 1 highlights the capabilities of the Keysight DP0011A differential active probe. Figure 6 outlines Keysight differential probes that will accurately capture the signal.

Serial buses	Standard 10:1 single-ended passive probe	Keysight DP0011A differential active probe, 500 MHz
LIN	✓	-
SENT	✓	-
CAN	-	✓
CAN FD	-	✓
CAN XL*	-	✓
FlexRay	-	✓
Automotive Ethernet*		✓

*Supported on Infiniium MXR-B oscilloscopes

Table 1. Serial bus capability comparisons

For the differential CAN, CAN FD, CAN XL, FlexRay, and automotive Ethernet protocols, we recommend using the DP0011A 500 MHz differential active probe with 1.7 MΩ / 1.5 pF of differential input impedance.

This probe provides accurate general-purpose differential signal measurements for today's high-speed power-related measurements such as motor drives, automotive differential bus measurements, and high-speed digital system designs.

Figure 6. The Keysight DP001XA differential active probes minimize circuit loading with a differential input resistance of 1.7 MΩ and a low input capacitance of 1.5 pF

Choosing the Right Oscilloscope Platform

To determine the oscilloscope platform that aligns best with your automotive serial bus measurement needs, consider your oscilloscope performance requirements, such as bandwidth, sample rate, memory, segmented memory, and speed of test, along with your automotive measurement requirements and budget constraints.

Testing classic PHY-layer in-vehicle networks

The InfiniiVision X-Series oscilloscopes are available in various models with bandwidths ranging from 70 MHz to 6 GHz. This platform uses a real-time operating system optimized for debugging the physical layer of CAN, CAN FD, LIN, FlexRay, and SENT serial bus designs.

Figure 7 illustrates that the InfiniiVision X-Series oscilloscope provides the fastest waveform update rates, 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 oscilloscopes also provide hardware-based decoding, making testing faster and more accurate than software-based decoding. Table 2 outlines each model’s specifications and measurement capabilities.

Figure 7. The InfiniiVision X-Series oscilloscopes help you capture elusive glitches and anomalies with uncompromised waveform update rates

Oscilloscope series		1000 X	3000 G	EXR	MXR B	UXR B
Analog channels		2 or 4	2 or 4	4, 8, or upgradeable	4, 8, or upgradeable	1, 2, 4, or upgradeable
Maximum bandwidth (all channels)		200 MHz	1 GHz	6 GHz	6 GHz	110 GHz
Maximum sample rate (all channels)		1 GSa/s	2.5 GSa/s	16 GSa/s	16 GSa/s	256 GSa/s
Maximum memory (all channels)		1 Mpts	2 Mpts	400 Mpts	400 Mpts	2 Gpts
Resolution		8 bits	8 bits	10 bits	10 bits	10 bits
Time-base accuracy		50 ppm	1.6 ppm	8 ppb	8 ppb	25 ppb
Screen display		7” WVGA*	8.5” WVGA*	15.6” Full HD	15.6” Full HD	15.4” XGA**
DDC / RTSA		Not available	Not available	Not available	40 MHz (standard)	160 MHz (standard)
Supported protocols	CAN / LIN	✓	✓	✓	✓	
	CAN FD / CAN XL			✓	✓	
	FlexRay / SENT		✓	✓	✓	
Advanced analysis	Mask test	✓	✓	✓	✓	
	Keysight Fault Hunter software			✓	✓	
	Keysight D9020AUTP high-speed automotive protocol decode software			✓	✓	✓
	Keysight AE6910T automotive Ethernet Tx test software			✓	✓	✓
	Keysight AE6920T automotive Ethernet Tx test software			✓	✓	✓

* WVGA represents a wide video graphics array.
** XGA represents an extended graphics array.

Table 2. Specific measurement capabilities of each Keysight oscilloscope series

Testing automotive Ethernet

Two governing standards bodies, IEEE and OPEN Alliance, set different data rates for conformance tests. The test requirements for automotive Ethernet applications are more stringent than those for traditional serial buses. Next-generation advanced drive-assistance systems (ADAS) require camera and radar systems with increasingly high resolution. These standards mean higher requirements for speed and bandwidth.

Figure 8 illustrates the migration from classic bus in-vehicle networks to an ADAS platform. Automotive Ethernet will become increasingly prevalent as in-vehicle networks transition from classic serial bus in-vehicle networks to support high-speed and low-latency digital communication for ADAS and connected car applications.

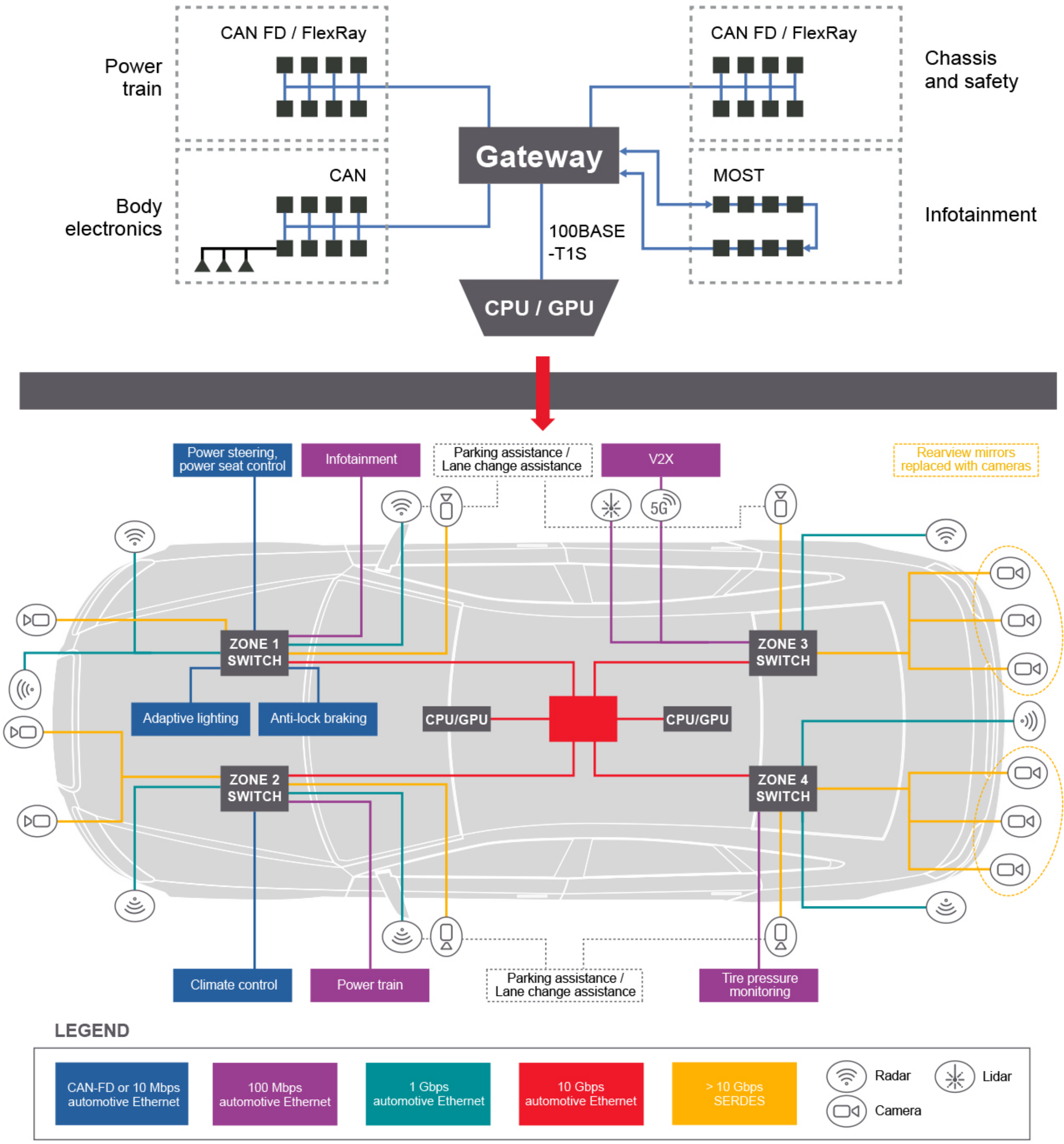


Figure 8. Example of automotive Ethernet in-vehicle networks

You can use the Keysight Infiniium MXR B-Series oscilloscopes for 10BASE-T1S to 5GBASE-T1 data rates compliance tests. For 10GBASE-TI automotive Ethernet data rates, the Keysight Infiniium UXR B-Series oscilloscopes are a future-proof investment for your bench as data rates continue to increase.

All tests require an oscilloscope and a network analyzer for the medium-dependent interface (MDI) return loss test and the MDI mode conversion loss test. Use an arbitrary waveform generator or function generator for transmitter distortion for 100 Mbps and 1 Gbps tests as outlined in Table 3 for data rates and required oscilloscope bandwidths.

Data rate	Minimum bandwidth	Additional equipment required
10BASE-T1S	500 MHz	Network analyzer
100BASE-T1	1 GHz	Vector network analyzer, arbitrary waveform generator
1000BASE-T1	2 GHz	Vector network analyzer, arbitrary waveform generator
2.5GBASE-T1	4 GHz	Vector network analyzer
5GBASE-T1	6 GHz	Vector network analyzer
10GBASE-T1	13 GHz	Vector network analyzer

Table 3. Infiniium MXR-B Series automotive Ethernet data rates

Learn more

How to Characterize Automotive Serial Buses – Use Case

How to Verify Automotive Ethernet Transmitter Compliance – Use Case

To learn more about Keysight measurement solutions, visit:

Infiniium Real-Time Oscilloscopes

InfiniiVision Oscilloscopes