APPLICATION NOTE

Oscilloscope Measurement Tools to Help Debug Automotive Serial Buses Quickly

Introduction

An oscilloscope has an inherent ability to characterize the analog quality of automotive serial buses such as CAN, CAN FD, LIN, SENT, PSI5, CXPI, and FlexRay. That is why engineers often use oscilloscopes to debug and characterize these signals. Performing analog characterization using an oscilloscope is known as taking physical-layer measurements. Serial bus protocol analyzers optimally perform measurements at the application layer. These instruments focus on providing trace flow of data at a higher abstraction level — but with little or no physical-layer measurement capability. A scope is not a replacement for a serial bus protocol analyzer. Engineers working on automotive serial bus applications typically have both.

Many oscilloscopes on the market offer automotive-focused options. However, Keysight InfiniiVision Series oscilloscopes offer unique measurement capabilities for debugging and characterizing the physical layer of automotive serial buses.

This application note explores the unique automotive measurement capabilities and advanced analysis features on InfiniiVision X-Series oscilloscopes to help you quickly debug and characterize the physical layer of automotive serial buses.

KEYSIGHT TECHNOLOGIES

Those capabilities include the following:

- CAN and CAN FD symbolic trigger and decode (based on .dbc file import)
- LIN symbolic trigger and decode (based on .ldf file import)
- CAN eye-diagram mask testing
- CAN FD eye-diagram mask testing
- FlexRay eye-diagram mask testing
- SENT mask pulse-shape physical layer testing
- dual-bus time-interleaved lister display
- hardware-based decoding for responsiveness
- decoding of all frames captured using segmented memory
- real-time frame / error counter with bus load measurement
- zone trigger to isolate occurrences of CAN bus arbitration
- signal charting (CAN, CAN FD, LIN, and SENT)

Fastest Oscilloscope Waveform Update Rate

The 3000 and 4000 X-Series oscilloscopes can update as fast as 1 million waveforms per second with Keysight's exclusive MegaZoom IV technology. InfiniiVision Series oscilloscopes remain responsive even when capturing long waveforms while using automatic deep acquisition memory, which automotive serial bus applications often require. Figure 1 shows that a responsive scope enhances the usability of the instrument, as well as its probability of capturing elusive events that may be problematic in automotive designs.

Waveform update rates can be extremely slow when using deep memory on conventional oscilloscopes. Not only does this make the scope difficult to use, but it decreases the probability of finding an infrequent glitch.

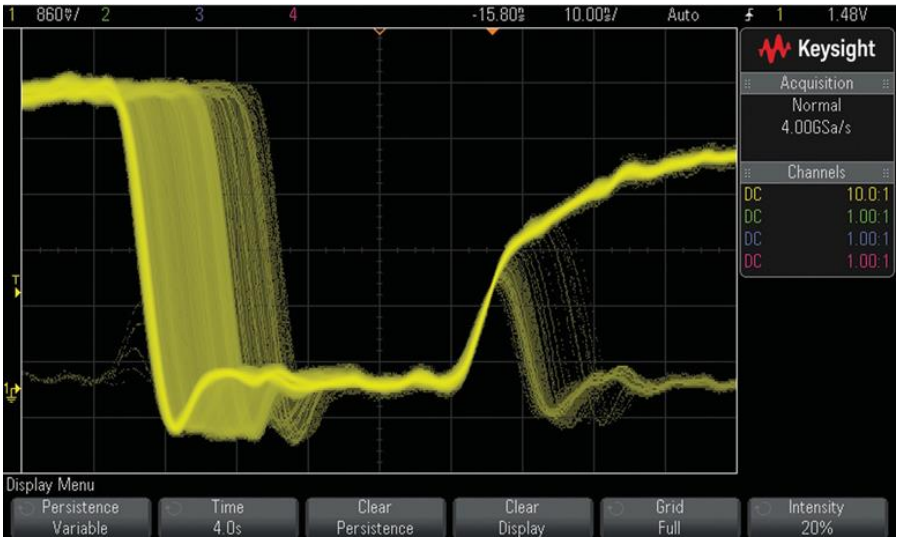

Figure 1. An update rate of 1 million waveforms per second easily captures infrequent glitches and jitter

Hardware-Based Decoding

InfiniiVision Series are the only oscilloscopes on the market that use hardware-based decoding of CAN, CAN FD, LIN, SENT, PSI5, CXPI, and FlexRay serial buses. Hardware-based decoding provides a virtual real-time update of the decode trace. This capability enhances the scope's probability of capturing and displaying infrequent serial bus communication errors, such as error frames and form, acknowledge, CRC, and stuff bit errors, as shown in Figure 2.

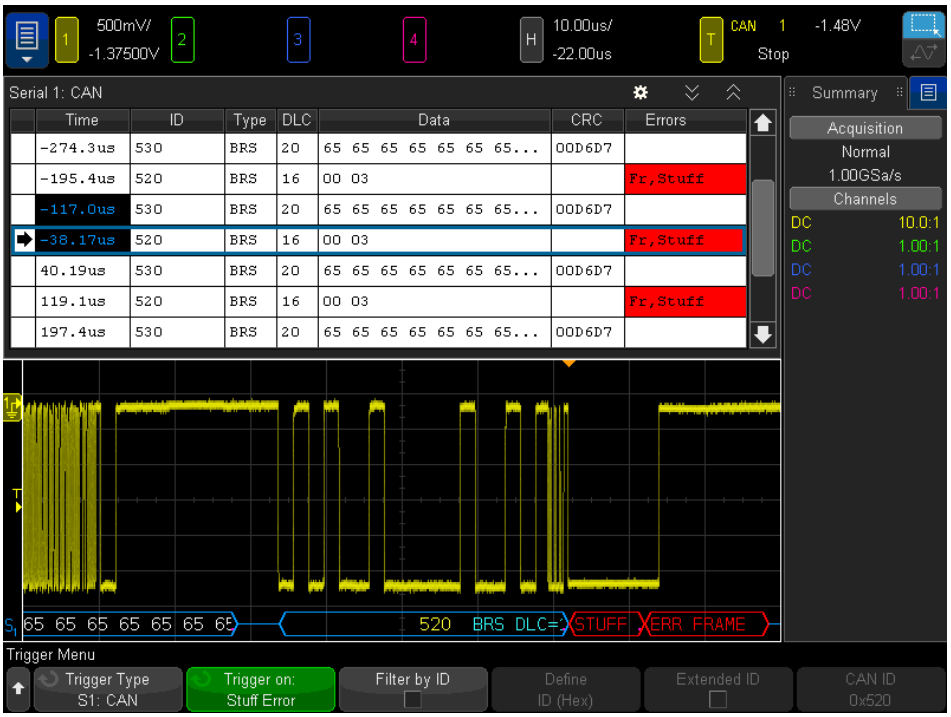

Figure 2. Hardware-based decoding captures and displays an infrequent CAN stuff bit error followed by an error frame

Symbolic Triggering and Decoding for CAN, CAN FD, and LIN

CAN-dbc and LIN-ldf symbolic decode and triggering are standard capabilities of the InfiniiVision 3000T, 4000, and 6000 X-Series' D3000AUTB / D4000AUTB / D6000AUTB options. Import an industry-standard .dbc or .ldf file that defines your CAN, CAN FD, or LIN network, and the oscilloscope will automatically display the symbolic messages and signals in human terms, as shown in Figure 3.

Figure 3. CAN-dbc symbolic trigger and decode

Eye-Diagram Mask Testing for CAN, CAN FD, and FlexRay

An oscilloscope eye diagram provides a view of the overall quality of the physical layer in one simple measurement. Figure 4 shows all recessive and dominant bits of the differential CAN bus overlaid to illustrate the worst-case amplitude and worst-case timing of all bits from all frames. The CAN eye-diagram measurement on InfiniiVision X-Series oscilloscopes shows amplitude variations of frames transmitted from various nodes in the system. It also clearly shows network propagation delays during the arbitration and acknowledgment phases of frames. You can also perform CAN FD eye diagram mask testing. CAN FD eye diagrams are based on the first 10 bits of the FD phase for all frames.

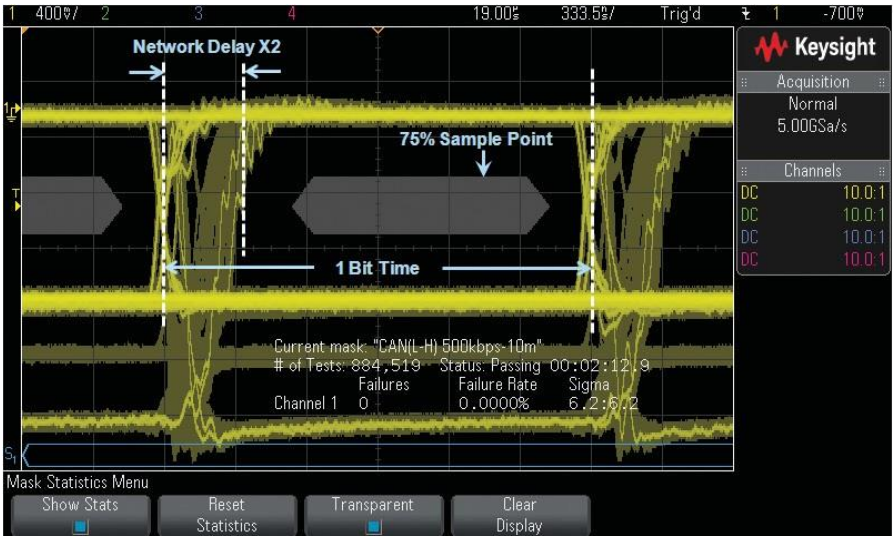

Figure 4. CAN eye-diagram mask testing shows amplitude variations and timing uncertainties, including network propagation delays, from all frames and bits

In addition to CAN and CAN FD eye-diagram mask testing, InfiniiVision Series oscilloscopes perform eye-diagram mask testing on the higher-speed differential FlexRay bus (3000, 4000, and 6000 X-Series only). Figure 5 shows an example of the TP4 eye-diagram mask test at the input of a FlexRay receiver. It shows significant edge jitter, slow rising and falling edges, and a shifted bit that intersects the pass / fail mask, causing mask test failures in this example.

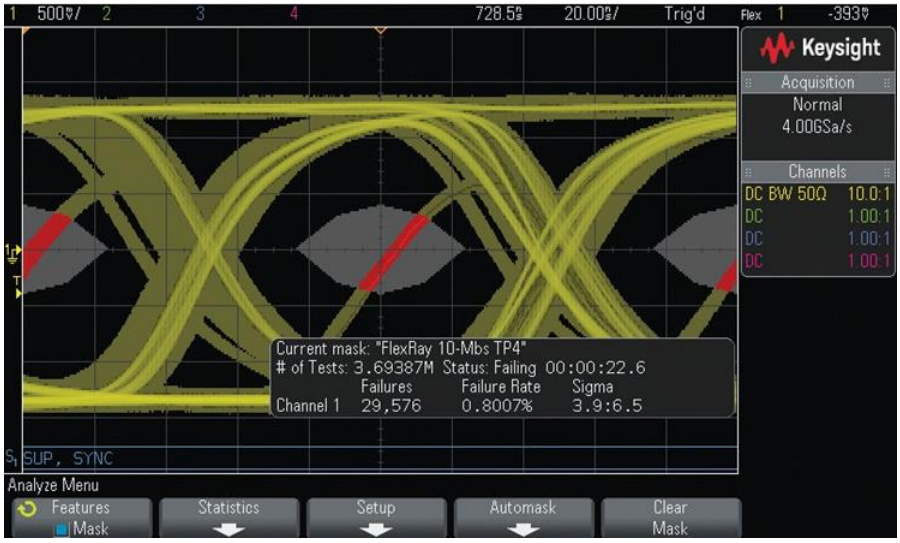

Figure 5. FlexRay eye-diagram mask test shows significant physical-layer issues when probed at the input of a particular FlexRay receiver

Mask testing based on software-intensive processing technology tends to be slow. The InfiniiVision scope's mask testing uses hardware-based technology, meaning it can perform up to 270,000 real-time waveform pass / fail tests per second. This capability makes your testing throughput orders of magnitude faster than it would be using conventional oscilloscope mask test solutions.

Dual-Bus Time-Interleaved Protocol Lister Display

Most oscilloscopes with serial bus options can display decoded data in two formats. One format shows one or more decode traces time-correlated to the captured waveform. This decode trace is useful when the scope's time base is set up to view a single frame. The time-correlated decode trace appears near the bottom of the scope's display (below the waveforms) on InfiniiVision Series oscilloscopes. The second decode format is what Keysight calls the "lister" display. The lister display shows a tabular list of decoded data with column labels based on the fields for the specific protocol.

Today's automobiles use multiple buses for control and monitoring, including the CAN, CAN FD, LIN, SENT, PSI5, CXPI, and FlexRay buses. Data sometimes need to pass from one bus to another. Automotive vendors use chips known as "gateways" to interchange data between buses. InfiniiVision 3000, 4000, and 6000 X Series oscilloscopes can display time-interleaved decoded data from two buses in the same lister table, as shown in Figure 6. The LIN bus frames are green, and the CAN bus frames are blue in this example. The time-interleaved lister display makes it easy to trace data that passes from one bus to another. Conventional scopes can display one table only or two tables side by side. It can be difficult to trace the data transfers between the buses, even with two tables displayed side by side.

Figure 6. Dual-bus time-interleaved lister display makes it easier to track data through CAN-to-LIN gateways

Real-Time Frame / Error Counter with Bus Utilization

InfiniiVision Series oscilloscopes can count the number of detected frames in real time (no dead time), including all frames, error frames (CAN, CAN FD), sync frames (FlexRay), and null frames (FlexRay). These frame counters run all the time, even when the scope's acquisition stops, as shown in Figure 7. Note that this is a real-time frame counter and that there is no oscilloscope dead time involved in this measurement.

Figure 7. Real-time frame counter and bus utilization measurement helps characterize CAN and FlexRay systems

A measure of bus utilization, or "bus load," in percentage is also important for characterizing CAN systems. This measures frame time relative to total time. The probability of bus contention and errors increases when the bus load gets too high in a CAN network. It also means that lower-priority messages may have a more difficult time gaining access to the bus.

Segmented Memory Acquisition with Frame Decoding in a Lister Display

Automotive engineers often need to capture multiple and consecutive — yet selective — frames of serial data. For example, they may want to capture each consecutive occurrence of SENT (Single Edge Nibble Transmission) errors without capturing everything in between. Without segmented memory acquisition, the alternative is to use a scope with extremely deep memory and then wade through all that memory after capturing a long record that includes all frames (not just selective frames). This process can be costly, slow, and difficult.

Engineers can set up InfiniiVision Series oscilloscopes to capture up to 1,000 segments (up to 50 segments on 1000 X-Series and up to 250 segments on 2000 X-Series) with precise time-tagging between each frame. Then they can review them individually with automatic decoding (time-correlated

decode trace and lister). This makes it easier to measure the time between occurrences of a particular error. It also allows engineers to track the sensor output data each time the error is transmitted, as shown in Figure 8. In this example of selectively capturing 1,000 consecutive SENT CRC errors, the last captured error occurred more than 200 seconds after the first captured error. Capturing this much data using conventional oscilloscope memory (non-segmented) would have required 300 Mpoints of acquisition memory.

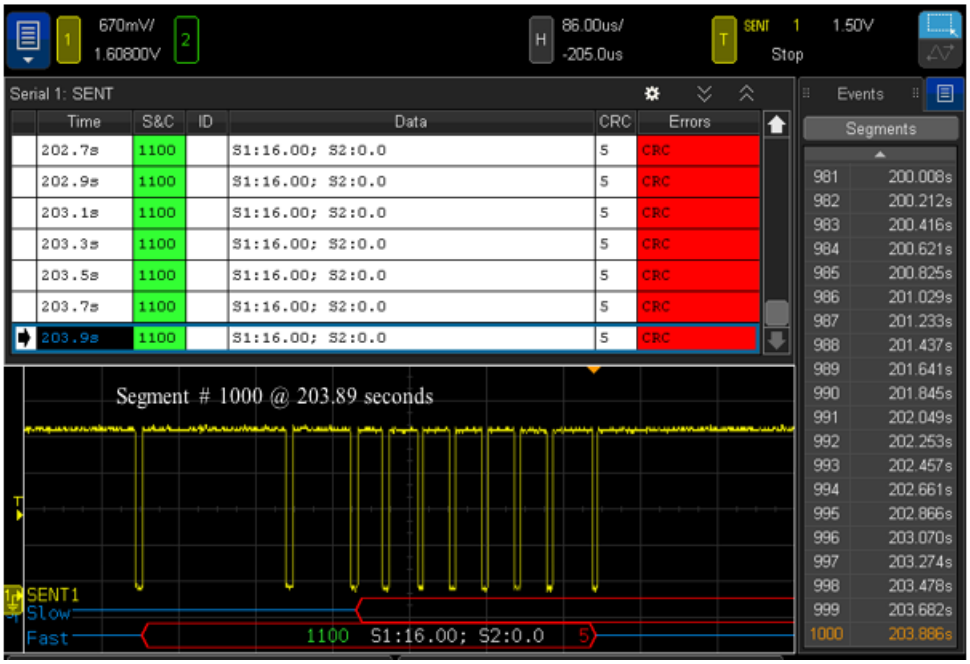

Figure 8. Segmented memory acquisition with automatic decoding selectively captures 1,000 consecutive occurrences of SENT fast-channel CRC errors with precise time-tagging between each occurrence

Segmented memory acquisition in the InfiniiVision Series oscilloscopes automatically decodes frames. InfiniiVision scopes are the only scopes that display all decoded frames from segmented acquisitions in the protocol lister display.

User-Definable Manchester / NRZ Trigger and Decode

The user-definable Manchester / non-return-to-zero (NRZ) option lets you trigger on and decode a broad range of automotive serial bus protocols, including the PSI5 sensor bus, wireless-entry key fobs, and radio-frequency-based tire pressure monitoring systems. With this user-definable serial bus option, you can define the encoding method (Manchester or NRZ), baud rate, number of start / sync bits, header field size, data field and word size, and trailer field size. Figure 9 shows an example of decoding a PSI5 sensor bus, which is based on Manchester encoding.

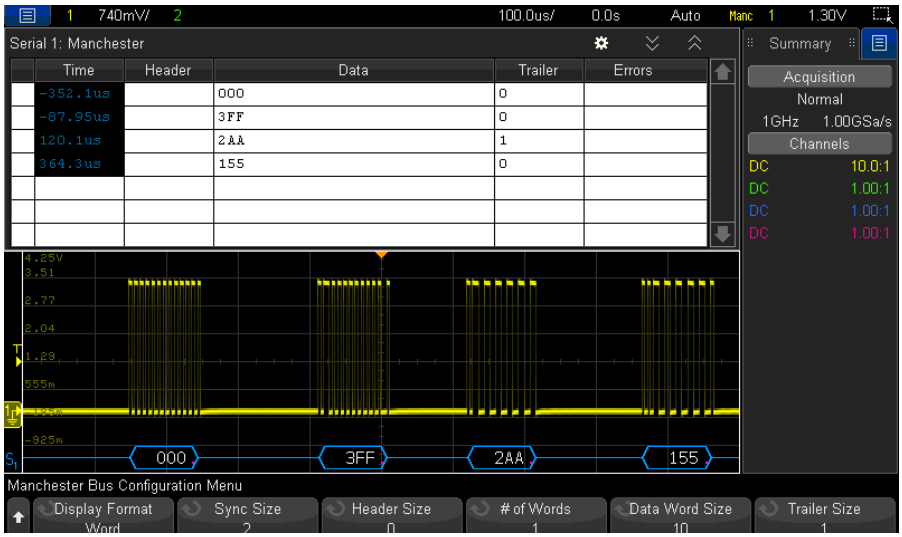

Figure 9. Triggering on and decoding an automotive PSI5 serial bus using the user-definable Manchester / NRZ option

Use Zone Triggering to Isolate and Characterize CAN Bus Arbitration

Identifying when CAN bus arbitration is occurring is easy if the oscilloscope's waveform update rate is fast. Triggering on occurrences of arbitration based on specific CAN messages is not so easy with most scopes. But the InfiniiVision oscilloscope's zone trigger capability lets you establish a "zone" where arbitration occurs (first few bits of each frame) while also qualifying the trigger condition on a specific frame ID (or symbolic message name), as shown in Figure 10. You can then use the oscilloscope's segmented memory acquisition to capture consecutive occurrences of arbitration to characterize how often it occurs.

Figure 10. Characterization CAN bus arbitration using the oscilloscope's zone triggering capability

Learn more

To learn more about InfiniiVision Series oscilloscopes, refer to the data sheets and application notes listed below.

Publication title	Publication number
InfiniiVision 1000 X-Series Oscilloscopes - Data Sheet	5992-1965EN
InfiniiVision 2000 X-Series Oscilloscopes - Data Sheet	5990-6618EN
InfiniiVision 3000T X-Series Oscilloscopes - Data Sheet	5992-0140EN
InfiniiVision 4000 X-Series Oscilloscopes - Data Sheet	5991-1103EN
InfiniiVision 6000 X-Series Oscilloscopes - Data Sheet	5991-4087EN
Automotive Software Package for InfiniiVision X-Series Oscilloscopes – Data Sheet	5992-3912EN
Serial Bus Options for InfiniiVision X-Series Oscilloscopes - Data Sheet	5990-6677EN
Extreme Temperature Probing Solutions for Oscilloscope Measurements - Data Sheet	5990-3504EN
Oscilloscope Waveform Update Rate Determines Ability to Capture Elusive Events - Application Note	5989-7885EN
CAN Eye-Diagram Mask Testing - Application Note	5991-0484EN
CAN FD Eye-Diagram Mask Testing - Application Note	5992-0437EN
Debug Automotive Designs Faster with CAN-dbc Symbolic Trigger and Decode - Application Note	5991-2847EN
FlexRay Physical Layer Eye-diagram Mask Testing - Application Note	5990-4923EN
Triggering on and Decoding the PSI5 Sensor Serial Bus - Application Note	5992-2269EN
Decoding Automotive Key Fob Communication based on Manchester-encoded ASK Modulation - Application Note	5992-2260EN
Using Oscilloscope Segmented Memory for Serial Bus Applications - Application Note	5990-5817EN
Characterizing CAN Bus Arbitration Using InfiniiVision 4000/6000 X-Series Oscilloscope - Application Note	5991-4166EN
InfiniiVision Application Bundles – Web Page	
InfiniiVision Automotive Better-Best Bundles – Flyer	7121-1082
Debugging Automotive & Electronic Signals using Oscilloscopes – Keysight University Course	

Summary

All of today's major oscilloscope vendors offer options for triggering on, decoding, and searching data on the CAN, LIN, SENT, PSI5, and FlexRay serial buses. So you have a choice. This application note shows you what's different about InfiniiVision Series oscilloscopes. The unique capabilities of Keysight's scopes will help you characterize and debug the physical layer of automotive serial buses faster.

Learn more at: www.keysight.com

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