Keysight Technologies
Oscilloscope Measurement Tools to Help Debug Automotive Serial Buses Faster

Application Note

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights

Introduction

The primary reason engineers use oscilloscopes to debug and characterize automotive serial buses, such as CAN, CAN FD, LIN, SENT, PSI5, CXPI and FlexRay, 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" measurements. Serial bus protocol analyzers are optimized at 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. A scope is not a replacement for a serial bus protocol analyzer, but neither is a serial bus protocol analyzer a replacement for a scope. Engineers working on automotive serial bus applications typically have both.

Although there are many oscilloscopes on the market today from multiple vendors that offer automotive-focused options, the Keysight Technologies, Inc. InfiniiVision Series oscilloscopes offer some unique measurement capabilities for debugging and characterizing the physical layer of automotive serial buses including:

Unique InfiniiVision capabilities [1]
- 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
- FlexRay conformance test software
- Dual-bus time-interleaved lister display
- Hardware-based decoding
- 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

Supported automotive protocols [2] (trigger and decode)
- CAN
- CAN FD
- LIN
- FlexRay
- SENT
- PSI5 (with user-definable Manchester/NRZ option)

1. Some features not available on 2000 X-Series models.
2. 2000 X-Series models only support CAN and LIN.

Fastest Oscilloscope Waveform Update Rate

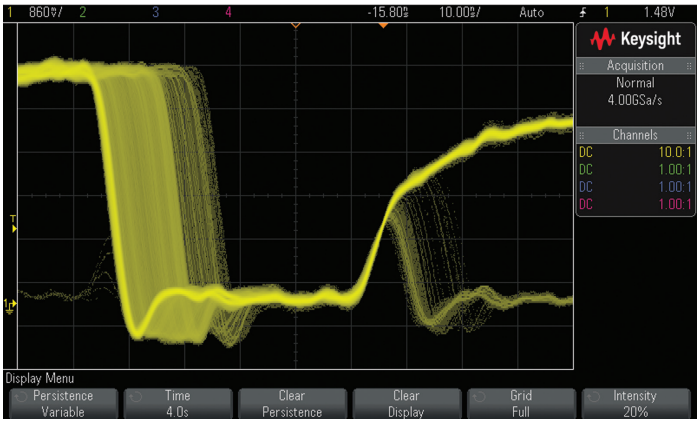

Figure 1. An update rate of 1,000,000 waveforms/sec easily captures infrequent glitches and jitter that other scopes miss.

With Keysight's exclusive MegaZoom IV technology, the 3000 and 4000 X-Series oscilloscopes can update waveforms as fast as 1,000,000 waveforms per second. Even when capturing long waveforms while using the scope's automatic deep acquisition memory – which is often required for automotive serial bus applications – Keysight's InfiniiVision Series oscilloscopes remain responsive. A responsive scope not only enhances the usability of the instrument, but it also enhances the scope's probability of capturing elusive events that may be problematic in an automotive design as shown in Figure 1. When using deep memory on other vendor's oscilloscopes, waveform update rates can be extremely slow. Not only does this make the scope difficult to use, but this also decreases the scope's probability of finding the infrequent glitch.

To learn more about oscilloscope waveform update rates, download Keysight's application note titled, "Oscilloscope Waveform Update Rate Determines Probability of Capturing Elusive Events" listed at the end of this document.

Hardware-based Decoding for CAN, CAN FD, LIN, SENT, PSI5, CXPI and FlexRay

Keysight's InfiniiVision Series oscilloscopes are the only oscilloscopes on the market today that utilize hardware-based decoding of the 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 enhances the scope's probability of capturing and displaying infrequent serial bus communication errors, such as stuff bit errors, form errors, acknowledge errors, CRC errors, and error frames as shown in Figure 2.

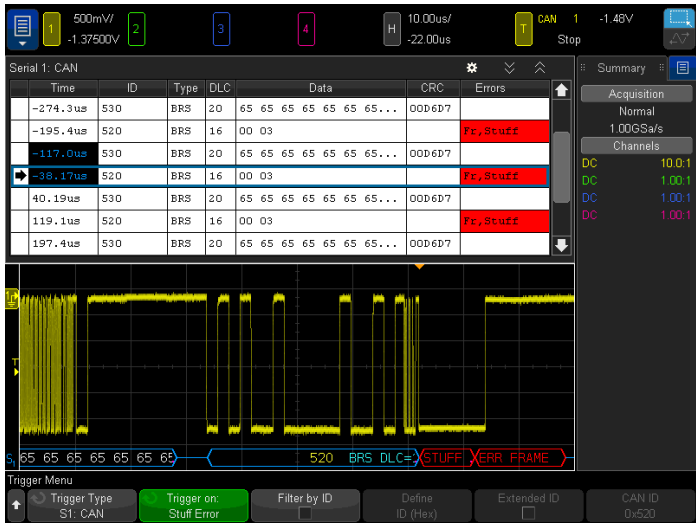

Figure 2. Hardware-based decoding captures and displays an infrequent CAN FD stuff bit error followed by an error frame that other scopes miss.

CAN, CAN FD, and LIN Symbolic-level Decoding and Triggering

A standard capability of the InfiniiVision 3000T, 4000 and 6000 X-Series' DSOXT3AUTO/DSOX4AUTO/DSOX6AUTO options is CAN and LIN-ldf symbolic decode and triggering. Simply import an industry-standard .dbc file or .ldf that defines your particular CAN and LIN network, and then the oscilloscope will automatically display messages and signals symbolically in human terms such as "Speed: 2.9016 krpm" as shown in Figure 3.

Figure 3. CAN-dbc symbolic decode and trigger.

CAN, CAN FD, and FlexRay Eye-diagram Mask Testing

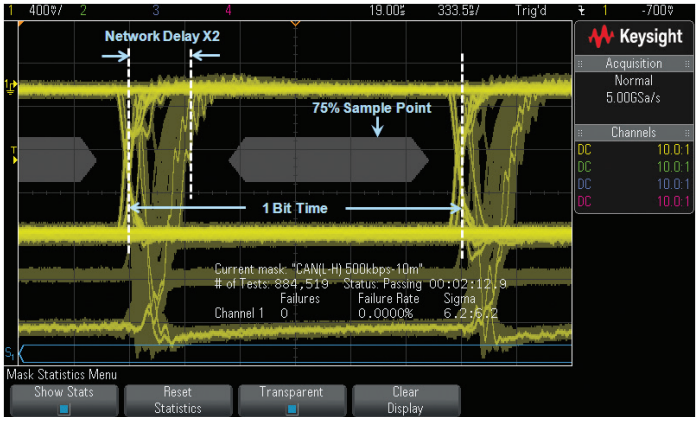

Figure 4. CAN eye-diagram mask testing shows amplitude variations and timing uncertainties, including network propagation delays, from all frames and all bits.

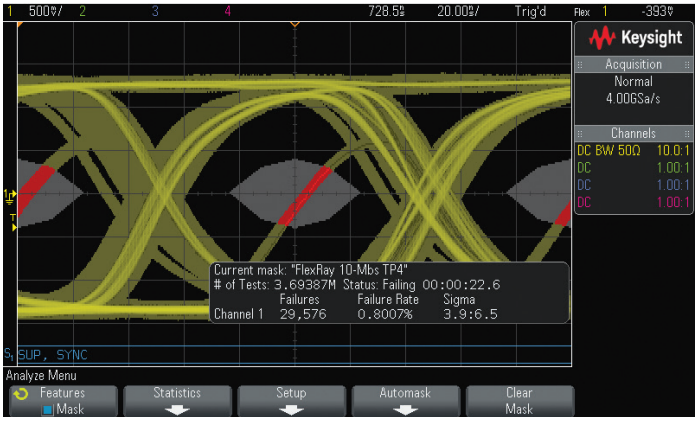

Figure 5. FlexRay eye-diagram mask test shows significant physical layer issues when probed at the input of a particular FlexRay receiver.

The “workhorse” bus in all of today’s automobiles is the differential CAN bus. Keysight’s InfiniiVision X-Series oscilloscopes are the only scopes on the market today that can perform pass/fail CAN eye-diagram measurements on the CAN bus.

An oscilloscope eye-diagram provides a composite measure of the overall quality of the physical layer in one simple measurement. All recessive and dominant bits of the differential CAN bus are overlaid to show worst-case amplitude and worst-case timing of all bits from all frames as shown in Figure 4. The CAN eye-diagram measurement on Keysight’s InfiniiVision X-Series oscilloscopes not only shows amplitude variations of frames transmitted from various nodes in the system, but it also clearly shows network propagation delays during the arbitration and acknowledgement phases of frames.

CAN FD eye-diagram mask testing can also be performed. CAN FD eye-diagrams are based on the first 10 bits of the FD phase for all frames.

In addition to CAN and CAN FD eye-diagram mask testing, Keysight’s InfiniiVision Series oscilloscopes can also 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 “TP4” eye-diagram mask test at the input of a FlexRay receiver. 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.

To learn more about eye-diagram testing on differential automotive buses, download Keysight’s application notes titled, “CAN Eye-diagram Mask Testing”, “CAN FD Eye-diagram Mask Testing” and “FlexRay Eye-diagram Mask Testing” listed at the end of this document.

Dual-bus Time-interleaved Protocol Lister Display

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

Real-time Frame Error Counter with Bus Utilization

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

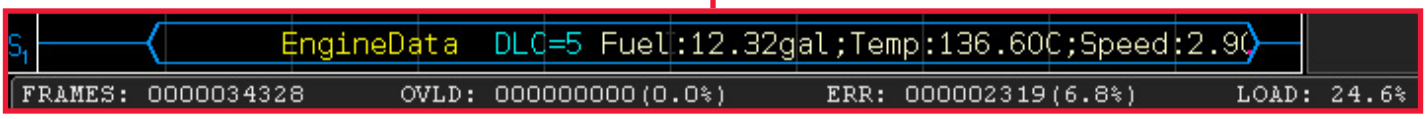

Figure 7a. Expanded view of the real-time frame counter.

Most oscilloscopes on the market today 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 primarily useful when the scope's timebase is set up to view a single frame. On Keysight's InfiniiVision Series oscilloscopes, the time-correlated decode trace is always shown near the bottom of the scope's display (below the waveforms). The second decode format is what Keysight calls the "lister" display. The lister display shows a tabular list of decoded data with columns that are clearly labeled based on the fields for the specific protocol.

Today's automobiles utilize multiple buses for control and monitoring including the CAN, CAN FD, LIN, SENT, PSI5, CXPI and FlexRay buses. Data within these buses sometimes needs to be passed from one bus to another. Automotive vendors use chips known as "gateways" to interchange data between buses. Keysight's 3000, 4000 and 6000 X-Series oscilloscopes are the only oscilloscopes on the market today that can display time-interleaved decoded data from two buses in the same lister table as shown in Figure 6. In this example, the LIN bus frames are shown in green while the CAN bus frames are shown in blue. The time-interleaved lister display makes it easy to trace data that is perhaps passed from one bus to another. Other scopes on the market can either display one table only, or two tables side-by-side. But even when two tables are displayed side-by-side, it can be very difficult to trace the data transfers between the buses.

For CAN and FlexRay applications, Keysight's InfiniiVision Series oscilloscopes are the only oscilloscopes on the market today that can count the number 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 has been stopped as shown in Figure 7, as well as the expanded view of the real-time frame counter shown in Figure 7a. Note that there is no oscilloscope dead-time involved in this measurement.

Also important for characterizing CAN systems is a measure of bus utilization, or "bus load", in percent. This basically measures frame time relative to total time. If "bus load" gets too high in a CAN network, this will increase the probability of bus contention and errors. 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

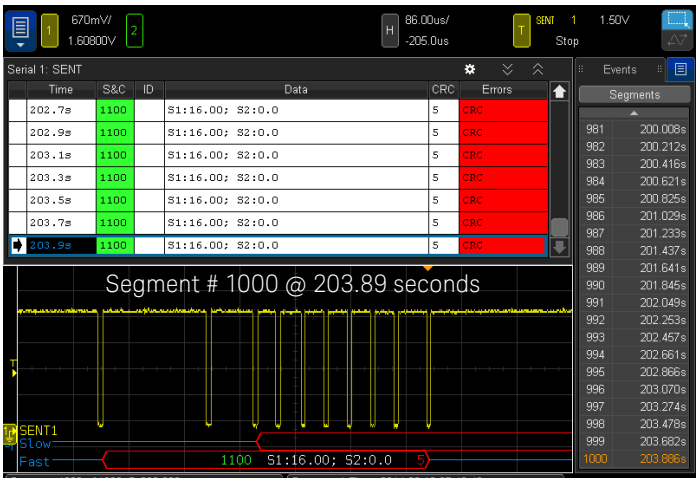

Figure 8. Segmented memory acquisition with automatic decoding selectively captures 1000 consecutive occurrences of SENT fast-channel CRC errors with precise time-tagging between each occurrence.

Automotive engineers often need to capture multiple and consecutive – yet selective – frames of serial data. For example, capture each consecutive occurrence of SENT (singe 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 very long record that includes all frames (not just selective frames). This can be costly, slow, and difficult.

Using Keysight's InfiniiVision Series oscilloscopes, engineers can set up the scope to capture up to 1000 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, and then review them individually with automatic decoding (time-correlated decode trace AND lister) as shown in Figure 8. For this measurement example of capturing consecutive occurrences of SENT fast-channel CRC errors, it makes it much easier to measure the time between occurrences of this particular error, and also allows you to track the sensor output data each time the error is transmitted. Note that in this example of selectively capturing 1000 consecutive SENT CRC errors, the last captured error occurred over 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.

Although segmented memory acquisition is also available on some other vendor's oscilloscopes, Keysight's implementation of segmented memory acquisition in the InfiniiVision Series oscilloscope not only automatically decodes frames, but is also the only scope that displays all decoded frames from segmented acquisitions in the protocol lister display.

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

User-definable Manchester/NRZ Trigger and Decode

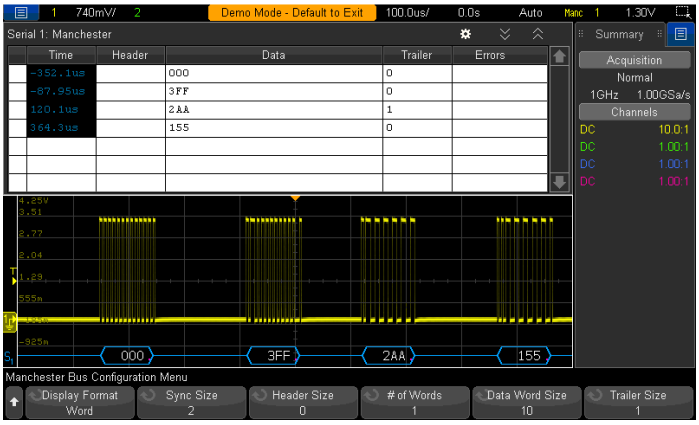

Figure 9. Triggering on and decoding an automotive PSI5 serial bus using the user-definable Manchester/NRZ option.

The user-definable Manchester/NRZ option can be used to trigger on and decode a broad range of automotive serial bus protocols, including the PSI5 sensor bus, wireless-entry key fobs, RF-based tire pressure monitoring systems (TPMS) and others. With this user-definable serial bus option, you can define the method of encoding (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.

FlexRay Physical Layer Conformance Test Software and with Complete Test Reporting

Isolated One

Reference:

Test Summary: Pass Test Description:

Test Limits: Overall Test = Pass Isolated "One" Pass

Result Details

Isolated One(Image) (See image)

Trial 1

Parameter	Description	Specification	Data Measurements	Pass/Fail
dBitLong	Longest Single bit	-	97.06 ns	Pass
dBitShort	Shortest Single bit	70.95 ns	95.49 ns	Pass
dBitLength Variation	Bit Asymmetry	7 ns	1.56 ns	Pass
dEdge01	Rising Edge Duration	50 ns	10.72 ns	Pass
dEdge10	Falling Edge Duration	50 ns	10.59 ns	Pass
dEdgeMax	Slowest Edge	50 ns	10.72 ns	Pass
dEdgeMax	Slowest Edge	50 ns	10.72 ns	Pass
uData1Top	Required maximal Lvl	330 mV	1.2973 V	Pass
Sq1	Voted Signal Quality	-	-	Pass

Trial 1: Isolated One(Image)

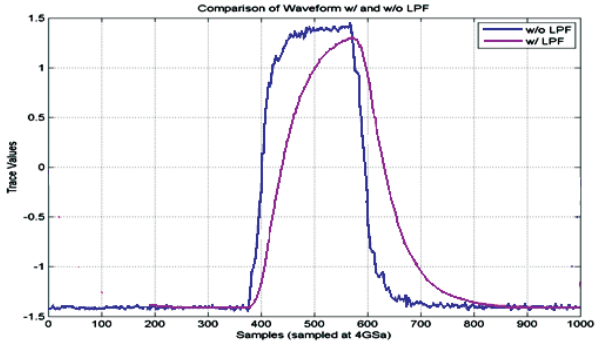

Figure 10. Test report from Keysight's FlexRay Physical Layer Conformance Test software package.

The FlexRay option on the Keysight InfiniiVision 3000, 4000 and 6000 X-Series oscilloscopes comes standard with the FlexRay Physical Layer Conformance Test software package that runs on a PC connected to the scope. This is the oscilloscope industry's most comprehensive FlexRay Physical Layer test package with complete test reporting as shown in Figure 10.

Use Zone Triggering to Isolate and Characterize CAN Bus Arbitration

Figure 11. Characterization CAN bus arbitration using the oscilloscope's zone triggering capability.

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 with the InfiniiVision oscilloscope's zone trigger capability, you can 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 11. You can then use the oscilloscope's segmented memory acquisition to capture consecutive occurrences of arbitration in order characterize how often it occurs.

To learn more about how to characterize CAN bus arbitration, download the "Characterizing CAN Bus Arbitration" application note listed at the end of this document.

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 choice. This document focused on showing you what's unique and different about Keysight's InfiniiVision Series oscilloscopes. Many of the unique capabilities of Keysight's scopes will help you characterize and debug the physical layer of automotive serial faster. To learn more about Keysight's InfiniiVision Series oscilloscopes, refer to the data sheets and application notes listed below. To view short videos focused on automotive applications, go to **www.keysight.com/find/scopes-auto**.

Related Literature

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
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

To download these documents, insert the publication number in the URL:
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Product website

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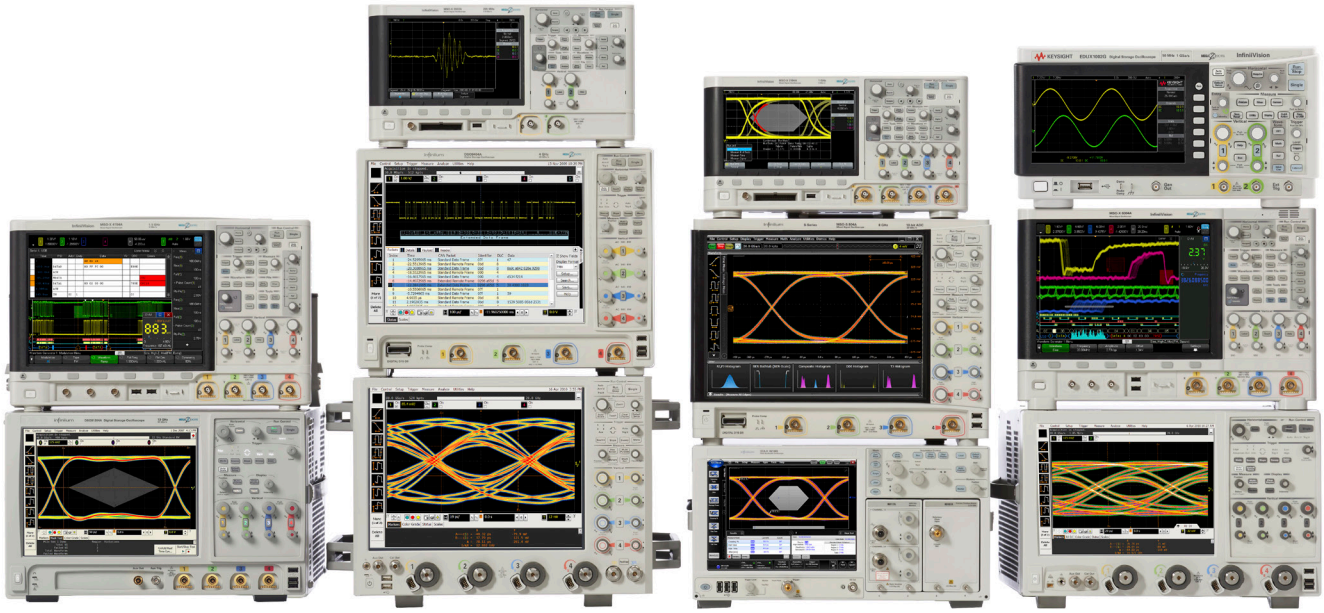

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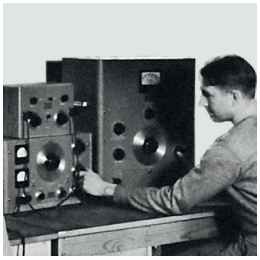
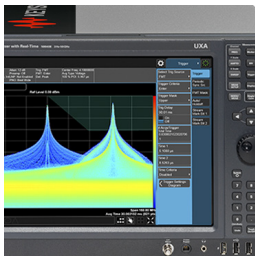


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