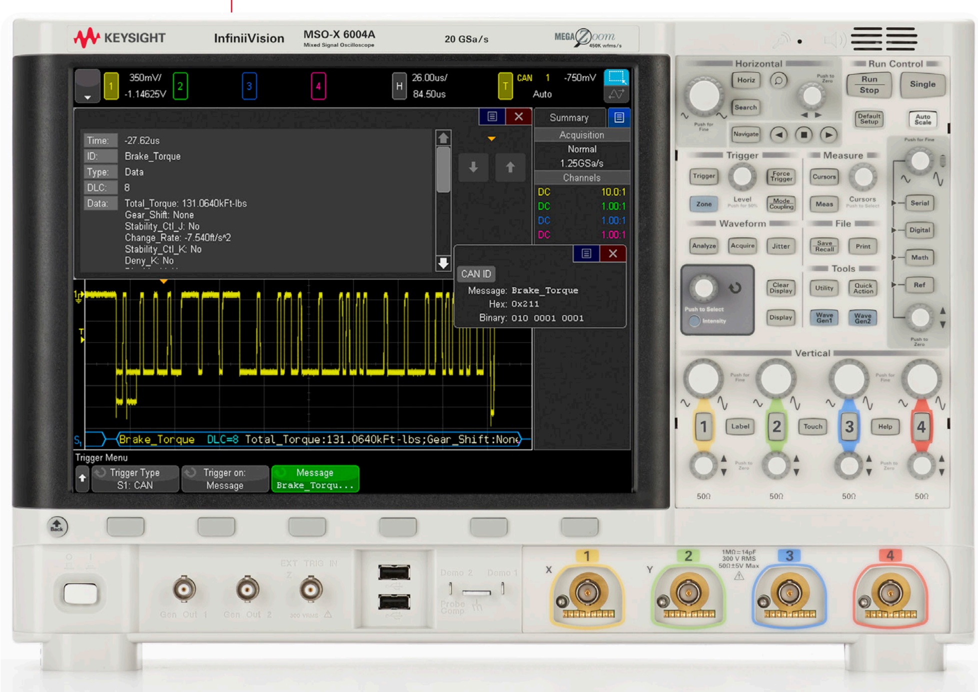
Keysight Technologies

Characterizing CAN Bus Arbitration Using InfiniiVision 4000/6000 X-Series Oscilloscope

Application Note



Introduction

The differential CAN bus, which is used extensively in automobiles for drive-train and body control, is based on asynchronous transmission of packets of data from multiple nodes in the system. The CAN bus is also used in many non-automotive applications including control of industrial machinery, as well as medical equipment. Because of the asynchronous nature of packet transmission, there are often collisions of data when two or more nodes begin transmission at the same time... or nearly same time. When collisions occur, although there is a non-destructive bit-wise arbitration process that determines which CAN message has the highest priority to continue data transmission, transmission of lower priority messages can be delayed. In addition, CAN bus error rates can theoretically increase based on the level of bus load and number nodes in the system. This directly affects the frequency-of-occurrence of data collisions. This application note will review the CAN non-destructive bit-wise arbitration process, and will use the InfiniiVision 4000 and 6000 X-Series oscilloscopes to show examples of the following:

- How to easily identify which symbolically-decoded CAN messages include arbitration
- How to synchronize on CAN messages that includes arbitration
- How to determine the relative occurrence of CAN messages that include arbitration

Non-destructive bit-wise arbitration

Non-destructive bit-wise arbitration is the process used by the asynchronous CAN bus to handle data collisions to ensure messages are received intact. Figure 1 is an illustration of how non-destructive bit-wise arbitration works in order to determine which transmitted frame has highest priority to continue transmitting bits when two or more frames begin transmitting data at nearly the same instance in time. "Non-destructive" simply means that one full frame always gets transmitted.

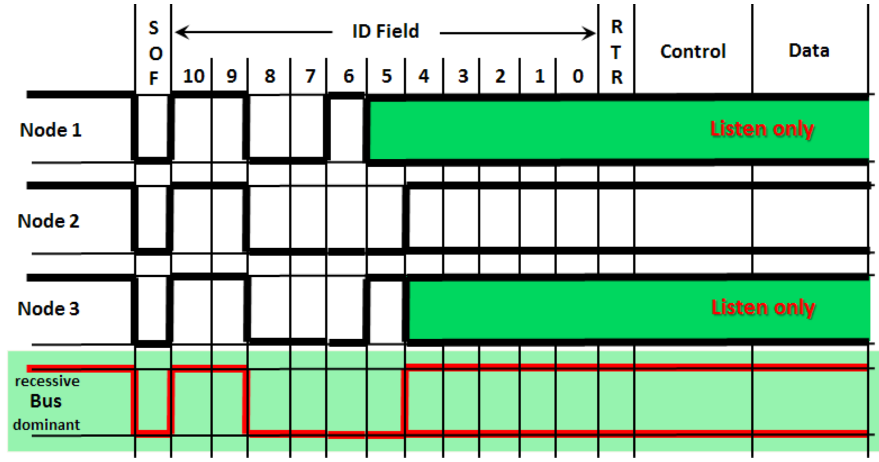


Figure 1. Non-destructive bit-wise arbitration.

The differential CAN bus essentially behaves as a logical "wired-AND" electrical network when monitored/viewed in a dominant-bit low format. In the dominant-bit low format, low-levels are interpreted as "zeros" while high-levels are interpreted as "ones". If all transmitted bits are high (one), then the bus is high. If one or more simultaneously transmitted bits are low (zero), which is the dominant state, then the bus is driven low.

The transmitting node with the lowest frame ID value will always win the arbitration contest since ID bits are always transmitted most-significant bits first. In this particular example, Node 2's frame ID consists of more zeros within the more significant bits of the 11-bit ID field. This means that this frame (from Node 2) has the lowest frame ID and will always win when competing against these specific frame IDs from Nodes 1 and 3, which have higher frame ID values.

Transmitting nodes not only transmit bits, but they also sample bits near the end of each bit time (typically sampled near the 75% bit-time point). If they transmit a "one" at the beginning of a bit time, but then sample a "zero" at the 75% bit-time point, they then know that there must be one or more nodes transmitting "zeros", which takes precedence. For example, during bit #6 Node 1 transmitted a "one", but then later sampled a "zero" on the differential bus (red trace). So at the beginning of bit #5, Node 1 relinquished control of the bus over to the other transmitting nodes. At this point, Node 1 must wait until the end of the currently transmitted frame for the next opportunity to attempt to transmit its data again.

Although non-destructive bit-wise arbitration works reliably, the tradeoff with asynchronous serial bus systems that are based on bit-wise arbitration, i.e. CAN, is that critical communication can often be delayed. In addition, if bus load is high (high duty cycle of frame transmission time relative to total bus time including idle time), high levels of bus contention can occur, thereby increasing theoretical bit error ratios (BER) as well as error recovery time. Automotive engineers typically like to keep their CAN system's bus load down to 50% or lower. With the ever increasing electronic complexity of today's automobiles, this is why some automotive communication networks are transitioning to CAN-FD to reduce bus load, and/or the time-triggered/synchronous FlexRay bus, where arbitration and bus load are non-issues. But while standard and extended CAN continue to be the primary serial bus used for control and monitoring in today's automobiles it is important to have tools that can identify and characterize them.

Let's now look at examples of identifying and characterizing when arbitration occurs using a Keysight Technologies, Inc. InfiniiVision 4000 or 6000 X-Series oscilloscope (DSO) to monitor the differential CAN bus.

Identifying when arbitration occurs

So what does arbitration look like? Referring back to Figure 1, the red trace represents a “logical” graphing of the differential CAN bus. A high is a high, a low is a low, and there is nothing in between, above, or below. This is what the differential bus might look like if you were using a logic analyzer or protocol analyzer to view this information. However with an oscilloscope you have more visibility into the quality of the bits transmitted and can further assess what is going on in the frame.

Figure 2 shows an example of capturing and displaying a CAN frame on Keysight’s InfiniiVision 4000 X-Series oscilloscope, which has the industry’s fastest waveform update rate (up to 1,000,000 waveforms/sec). Fast waveform update rate is required in order to capture infrequent occurrences of arbitration. In this particular example, we have set up the scope to trigger on a particular message and then decoded the bus symbolically by importing a .dbc file that defines this particular CAN network. The message that the scope was triggering on in this example is labeled “*Brake_Torque*”, which directly relates to frame ID 0x211$_{\text{(HEX)}}$ or 010 0001 0001$_{\text{(Binary)}}$. Arbitration sometimes occurred during this message as evidenced by the lower low-level bits that can be observed near the beginning of the frame/message.

Also notice there is another low-level bit transmitted at the end of the frame. This is known as an ‘ACK’ or acknowledge bit. This ACK bit is transmitted at the end of each frame when all other nodes in the system acknowledge that the just-transmitted frame was valid. When all nodes pull on the bus to drive it to a dominant-low level, since multiple nodes are pulling down on the bus simultaneously, more current flows to cause the bus to go to a lower low level.

The same phenomenon happens at the beginning of the frame if more than one node initially tries to gain access to the bus as shown in Figure 3, which shows a zoomed-in view of the beginning of this message (*Brake_Torque*). With the scope’s timebase set at 2 µs/div, which is equivalent to 1 bit/div, we can actually see three distinct low levels of this single-shot acquisition near the beginning of the frame. This means that there are at least three nodes contending for dominance of the bus. After the first five most- significant bits of the ID field have been transmitted, frame ID 0x211 takes full control and then the amplitude of the dominant-low levels settle to the level that frame ID 0x211 alone generates (a normal low level). So how often is arbitration occurring during this particular message (*Brake_Torque*)?

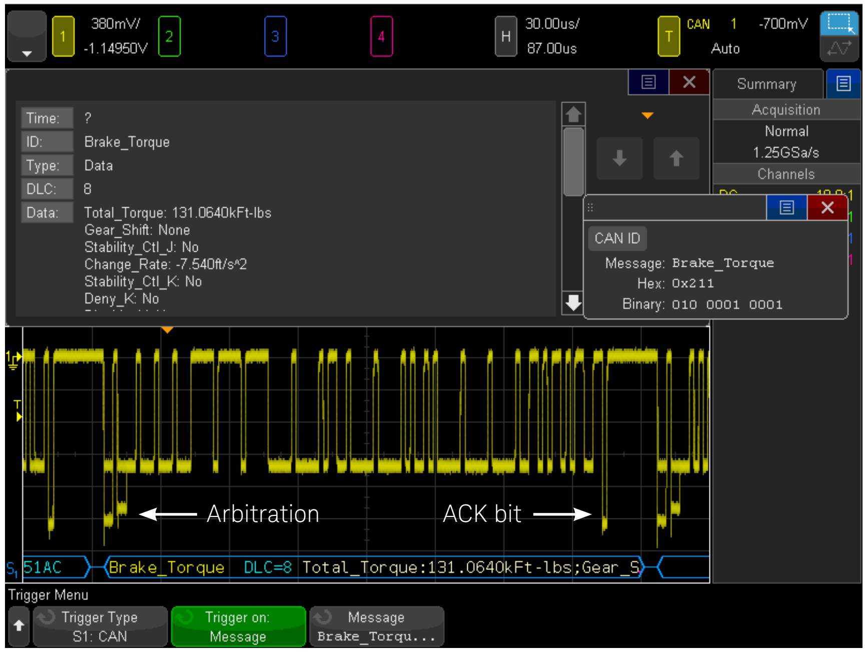


Figure 2. Viewing evidence of arbitration on an oscilloscope.

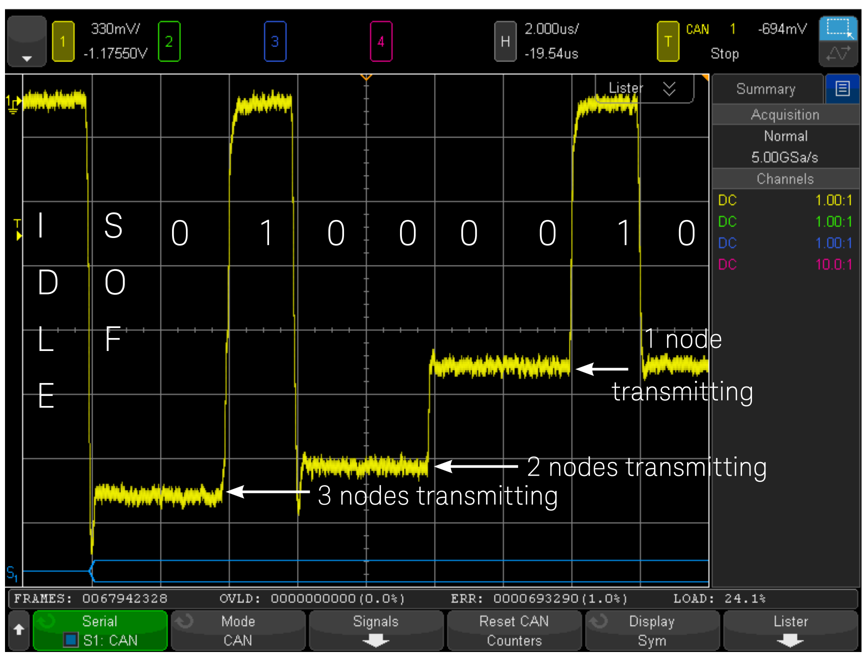


Figure 3. Zoomed-in view of arbitrating bits during message: Brake_Torque

Triggering on arbitration

The first step in determining the frequency-of-occurrence of arbitration is to set up the scope to uniquely synchronize (trigger) on occurrences of Message: *Brake_Torque* — but only when arbitration occurs. This means that the scope must be able to filter-out occurrences of this message when arbitration doesn't occur.

Triggering on Frame ID: 0x211$_{(HEX)}$ is relatively easy when using an oscilloscope with a CAN trigger/decode option. Lots of scopes on the market today have this capability. And it's even easier to trigger at a higher-abstraction "message" level if the oscilloscope has the ability to import a .dbc file in order to trigger and decode on the CAN bus symbolically. There are fewer scopes on the market today that have this capability. But symbolic-level triggering is possible with Keysight's InfiniiVision 4000 and 6000 X-Series oscilloscopes. However, triggering on either Frame ID: 0x211$_{(HEX)}$ or Message: *Brake_Torque*, but only when arbitration occurs is either difficult or impossible with most scopes on the market today. With InfiniiScan Zone touch triggering in the InfiniiVision 4000 and 6000 X-Series it is not only possible but extremely easy to narrow the trigger to a single transmitted message only when arbitration occurs.

Figure 4 shows an example of the scope now triggering uniquely on Message: *Brake_Torque*, but only when arbitration occurs. The scope was first set up to trigger on Message: *Brake_Torque*. Triggering was then further qualified by drawing a zone (box) around the lower-level bits near the beginning of this frame using the scope's capacitive touch-screen display. Note the yellow-shaded box near the lower left-hand corner of the scope's display. The zone's qualifier was then selected as "Must Intersect".

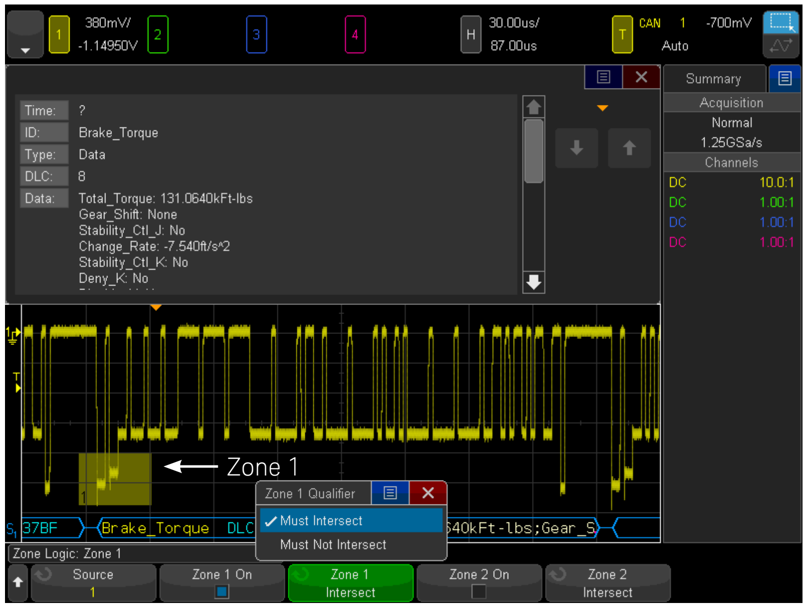


Figure 4. Using Zone Trigger to synchronize on arbitration bits.

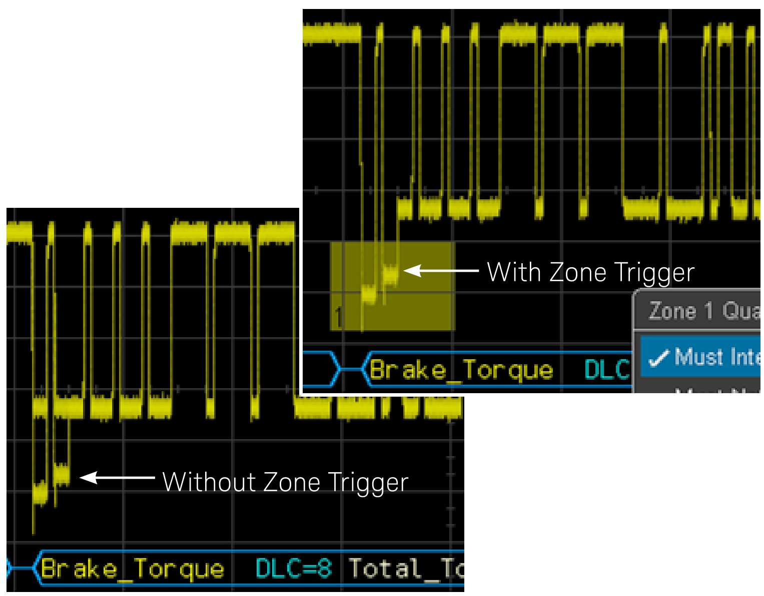


Figure 5. Comparing triggering on message: Brake_Torque with and without Zone trigger.

Figure 5 shows a zoomed-in view of the beginning of message: Brake_Torque to compare triggering with and without zone trigger. The lower screen-image of Figure 5 shows triggering ***without*** zone trigger. In this case we can see that the first few bits of this message exhibit lower low levels (arbitration occurring), as well as normal low levels (arbitration not occurring).

The upper screen–image of Figure 5 shows triggering ***with*** zone trigger. Now we can see that the first few bits always exhibit lower low levels. This means that we have locked-in on just instances of transmissions of this message when it experiences arbitration with other messages in the system. We have effectively filtered-out instances when arbitration doesn't occur.

Note that if we had wanted the scope to uniquely trigger on this particular message, but only when arbitration *didn't* occur, then we could have selected "Must Not Intersect" as our zone qualifier. In this case, the scope would have filtered-out the arbitrated lower low-level bits, and then only displayed frames with non-arbitrated ID bits.

To learn more about InfiniiScan Zone trigger, refer to the application note listed at the end of this document.

Now that we have the oscilloscope set up to uniquely trigger on this frame (Message: *Brake_Torque*), but only when arbitration occurs, let's now talk about how to characterize the frequency-of-occurrence of arbitration using the scope's ***segmented memory*** acquisition mode.

Using Segmented Memory to Characterize Frequency-of-Occurrence of Arbitration

One "brute force" method of characterizing how often arbitration occurs during a particular message would be to obtain a scope that has extremely deep memory, and then capture a long stream of continuous CAN data transmission. The difficult task then would be to manually scroll through the captured data and visually look for the arbitrated bits within a particular frame, and then measure the time between occurrences. This method is slow and tedious – and also requires purchasing or leasing a very expensive high performance oscilloscope with hundreds of megabytes of acquisition memory.

Capturing a continuous stream of transmitted CAN data is an inefficient use of the scope's acquisition memory. Segmented memory acquisition optimizes your oscilloscope's memory. You can set up the scope to selectively capture just the frame/message of interest while consuming a small portion of the scope's acquisition memory for each and every consecutive occurrence of the message that the scope is triggering on. This essentially extends the total time-span that the oscilloscope can capture.

Figure 6 shows an example of capturing 100 consecutive occurrences of Message: *Brake_Torque*, but only when arbitration occurred (using zone trigger as the message/frame arbitration qualifier). The symbolic protocol lister in the top half of the scope's display shows us the time between each occurrence of arbitration. Note that we could have also set up the protocol lister to display the absolute time of each occurrence of arbitration relative to the first captured event. We also have the ability to scroll through each individual frame in order to view the quality of each digitized waveform.

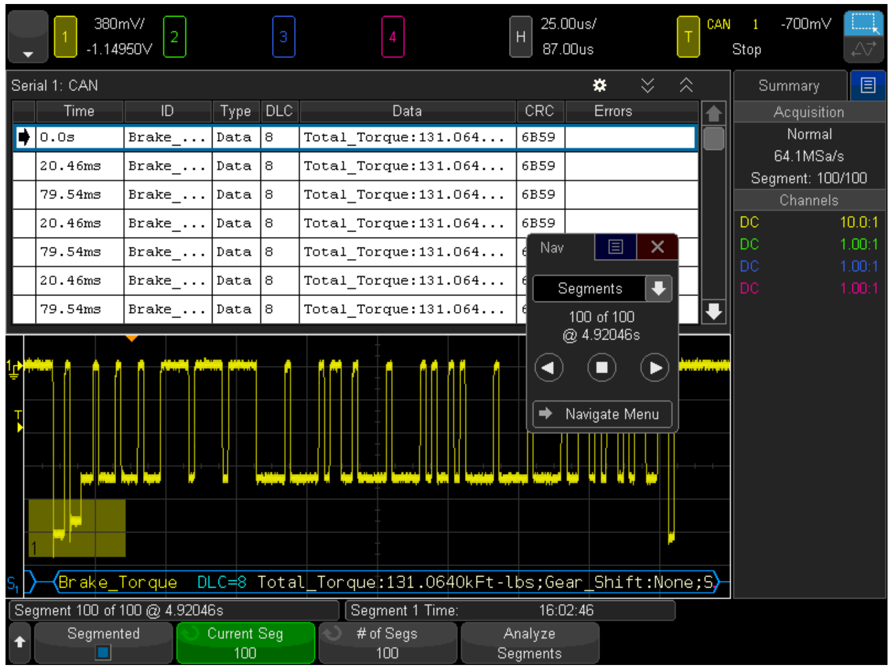


Figure 6. Using Segmented Memory to characterize the frequency-of-occurrence of arbitration.

In this list of 100 consecutive occurrences of Message: *Brake_Torque* that includes arbitration, the last captured frame (segment #100) occurred nearly 5 seconds after the first captured frame (segment #1). Capturing this much waveform data using continuous oscilloscope acquisition (non-segmented) would have required over 300 M points of memory!

Note that segmented memory acquisition can also be used to characterize delays of lower priority messages (messages that always lose the arbitration contest). In this case, you would set up the scope to trigger on a lower priority message (lower ID value) without using zone trigger. Using segmented memory acquisition, the scope would then capture every sequential occurrence of the higher priority message along with time-tagging of each message.

The learn more about ***segmented memory*** acquisition, refer to the application note listed at the end of this document.

Summary

A critical measurement tool used by most engineers in the automotive industry to characterize the physical layer of the differential CAN bus is a digital storage oscilloscope. This application note has presented you with measurement techniques available in Keysight's InfiniiVision 4000 and 6000 X-Series oscilloscopes to test and debug automotive systems.

As shown in this document, characterizing the frequency-of-occurrence of CAN arbitration within a particular frame/message required the following oscilloscope measurement capabilities:

- Fast waveform update rate to capture infrequent occurrences of arbitration
- CAN frame/message triggering to synchronize acquisitions on particular frames/messages
- Zone triggering to isolate/synchronize the scope's acquisition on just frames/messages that exhibit arbitration
- Segmented memory acquisition with precise time-tagging to selectively capture multiple and consecutive occurrences of frames/messages with arbitration

Related Literature

Publication title	Publication type	Publication number
Keysight InfiniiVision 4000 X-Series Oscilloscopes (200 MHz to 1.5 GHz)	Data sheet	5990-1103EN
Keysight InfiniiVision 6000 X-Series Oscilloscopes (1 GHz to 6 GHz)	Data sheet	5991-4087EN
Serial Bus Options for InfiniiVision X-Series Oscilloscopes	Data sheet	5990-6677EN
InfiniiVision Oscilloscope Probes & Accessories	Data sheet	5968-8153EN
Automotive Serial Bus Testing using InfiniiVision X-Series and Infiniium S-Series Oscilloscopes	Application note	5991-4038EN
Oscilloscope Measurement Tools to Help Debug Automotive Serial Buses Faster	Application note	5991-0512EN
CAN Eye-diagram Mask Testing	Application note	5991-0484EN
Triggering on Infrequent Anomalies and Complex Signals using Zone Trigger	**Application note**	**5991-1107EN**
Using Segmented Memory for Serial Bus Applications	**Application note**	**5990-5817EN**

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

Product web site

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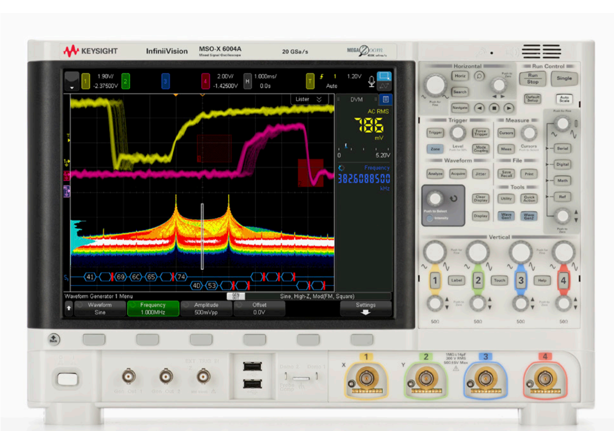

The InfiniiVision 6000 X-Series (1 GHz- 6 GHZ, 20 MSa/s sample rate and 4 Mpt memory) can be optioned with the DSOX6AUTO that includes the CAN triggering a decoding discussed in this application note.

The InfiniiVision 4000 X-Series (200 MHz- 1.5 GHZ, 5 GSa/s sample rate and 4 Mpt memory) can be optioned with the DSOX4AUTO that includes the CAN triggering a decoding discussed in this application note.

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