

Keysight Technologies

# CAN FD Eye-Diagram Mask Testing

Using a Keysight InfiniiVision 3000T  
or 4000 X-Series Oscilloscope

Application Note

## Introduction

Eye-diagram mask testing is used in a broad range of today's serial bus applications. An eye-diagram is basically an infinite persisted overlay of all bits captured by an oscilloscope to show when bits are valid. This provides a composite picture of the overall quality of a system's physical layer characteristics, which includes amplitude variations, timing uncertainties, and infrequent signal anomalies. Eye-diagram testing is especially important for higher speed buses such as the new CAN FD serial bus.

Eye-diagram testing can be performed on a CAN FD differential bus using a Keysight Technologies InfiniiVision 3000T or 4000 X-Series oscilloscope licensed with the DSOXT3AUTO or DSOX4AUTO trigger and decode option (CAN, CAN FD, & LIN), along with the DSOX3MASK or DSOX4MASK mask test option. Various CAN FD mask files based on the data phase baud rate and differential probing polarity (dominant-bit high or dominant-bit low) can be downloaded from Keysight's website at no charge. The following CAN FD mask files are available:

- CAN-FD (L-H) 500k-4M.msk
- CAN-FD (L-H) 500k-5M.msk
- CAN-FD (L-H) 500k-6M.msk
- CAN-FD (L-H) 500k-8M.msk
- CAN-FD (L-H) 500k-10M.msk
- CAN-FD (H-L) 500k-4M.msk
- CAN-FD (H-L) 500k-5M.msk
- CAN-FD (H-L) 500k-6M.msk
- CAN-FD (H-L) 500k-8M.msk
- CAN-FD (H-L) 500k-10M.msk

If you are probing the differential CAN FD bus to view dominant-bit low, then you should use one the mask files with "L-H" in the mask file name. If you are probing the bus to view dominant-bit high, then you should use one the mask files with "H-L" in the mask file name. Probing polarity will be discussed in the next section of this document.

CAN FD eye-diagram mask testing only supports CAN FD buses with a base-rate (arbitration phase) of 500kbps and FD rates (data phase) ranging from 4Mbps up to 10Mbps. So for example, if your CAN FD data rate is 10Mbps, then you should use one the mask files with "500k-10M" in the file name.

CAN FD eye-diagram mask testing does not test every bit. It only tests the first 10 bits in the FD data phase of all CAN FD frames. In other words; only frames with a bit-rate switch (BRS) bit. 10 bits covers worst-case resynchronization, which can happen if two consecutive stuff bits occur. This will test for worst-case clock stability and jitter over 10 bit periods. Although not every bit in the FD data phase are tested, overlaying just the first 10 bits of the FD data phase from all frames will show waveform characteristics of received bits from all nodes in the system. So if one of the FD nodes in your system exhibits physical layer problems, such as reduced amplitudes, slow edge speeds, noise, etc., these characteristics will show up in the eye-diagram by testing just the first 10 bits of the FD data phase.

Eye-diagram mask testing can also be performed on "classic" CAN 2.0 signals. Refer to Keysight's application note titled, "CAN 2.0 Eye-diagram Mask Testing" listed at the end of this document to learn more about testing CAN 2.0 signals (non-FD).

## Probing the Differential CAN FD Bus

CAN FD eye-diagram mask testing is based on capturing and overlaying recessive and dominant bits on the differential bus. The differential bus must be probed using a differential active probe. Keysight recommends using the N2818A 200-MHz differential active probe shown in Figure 1. This probe includes a Keysight AutoProbe interface that automatically sets the oscilloscope's input impedance (50-Ω) and attenuation factor (10:1), and also provides power to the active probe.

If you need to connect to SubD-DB9 connectors in your system, Keysight also offers the CAN/FlexRay SubD-DB9 probe head (Part number 0960-2926) shown in the inset photo of Figure 1. This optional probe head adapter allows you to easily connect to your CAN, CAN FD, and/or FlexRay differential buses.

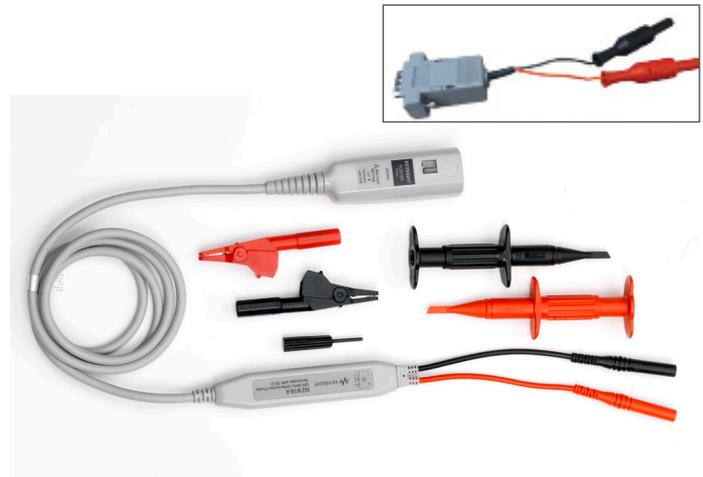


Figure 1: N2818A 200-MHz Differential Active Probe and SubD-DB9 Probe Head.

A differential active probe allows you to view signals on the differential CAN FD bus in either a dominant-bit high or dominant-bit low format. And CAN FD eye-diagram mask testing can be performed using either polarity of probing. To observe signals as dominant-bit high, connect the “+” input (red lead) of the differential probe to CAN\_H and the “-” input (black lead) of the probe to CAN\_L. Figure 2 shows a differential CAN FD waveform in the dominant-bit high format.

To observe signals in the dominant-bit low format, connect the “+” input (red lead) of the differential probe to CAN\_L and the “-” input (black lead) of the probe to CAN\_H. Although connecting the differential probe to the bus in this manner may sound backwards and perhaps unintuitive, timing diagrams of CAN FD signals are typically shown in a dominant-bit low format. In this format, bus idle level is always high (recessive). Also, during transmission of CAN FD frames, high-level signals (recessive bits) will always be interpreted as “1s”, while low-level signals (dominant bits) will always be interpreted as “0s”. Figure 3 shows a differential CAN waveform in the dominant-bit low format. This is the preferred method of probing by most engineers today.

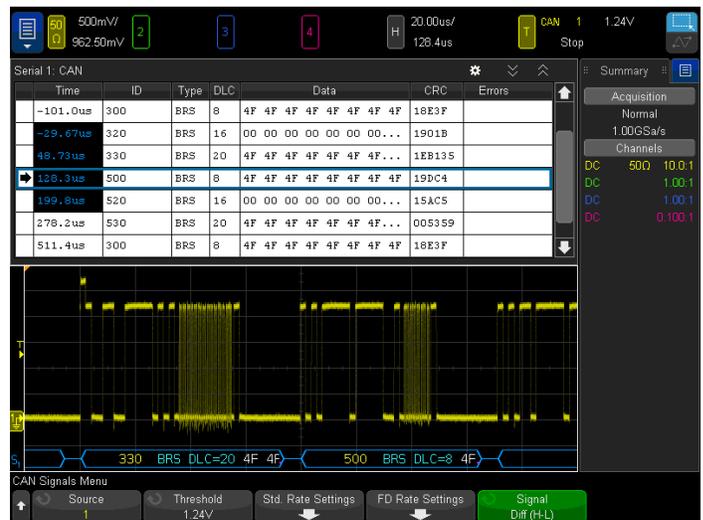


Figure 2: Probing the differential CAN FD bus to show dominant-bit high.

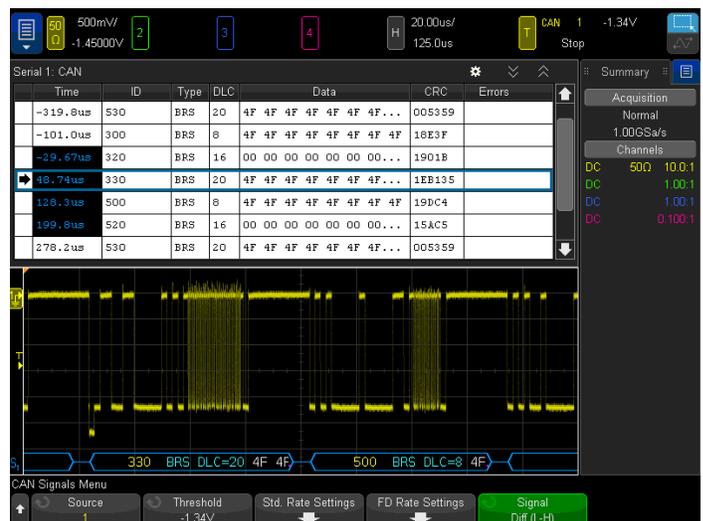


Figure 3: Probing the differential CAN FD bus to show dominant-bit low.

## Step-by-Step Instructions to Perform a CAN FD Eye-diagram Mask Test

To perform a CAN FD eye-diagram mask test, first turn off all channels of the oscilloscope except for the input channel that is connected to the CAN FD differential bus. If you begin with a **Default Setup**, only channel-1 will be turned on. Alternatively, you can begin with the oscilloscope already set up and triggering on the differential CAN FD bus. To begin execution of a CAN FD eye-diagram mask test, do the following:

1. Insert your USB memory device (with the appropriate mask file) into the scope's front panel USB port.
2. Press the **[Save/Recall]** front panel key; then press the **Recall** softkey.
3. Press the **Recall: XXXX** softkey; then select **Mask (\*.msk)** as the type of file to recall.
4. Press the **Location** (or **Press to go**, or **load from**) softkey; then navigate to the appropriate mask file based on FD baud rate and probing polarity (L-H = dominant bit low, H-L = dominant bit high).
5. Press the **Press to Recall** softkey to begin a CAN FD eye-diagram mask test.

When the mask file is recalled, the scope will automatically set itself up (timebase, vertical, and trigger settings) to display overlaid CAN FD bits across the center five divisions of the scope's display. During this special sequencing test, timebase settings and timing cursors cannot be used. To exit a CAN FD eye-diagram mask test, either turn off mask testing or press **Clear Mask** in the scope's **Analyze-Mask** menu. When the test is exited, the scope will restore most oscilloscope settings to the state they were in prior to beginning the test. However, triggering is not restored and will remain set to trigger on the trailing edge of bit-rate switch (BRS) bits, which is the beginning of the FD data rate phase, using the scope's Pulse-width trigger mode.



Figure 4: CAN FD eye-diagram mask test on 10Mbps data phase bits based on probing the bus to view dominant-bit low.

## Interpreting the Eye

Figure 4 shows a CAN FD eye-diagram mask test based on an arbitration phase baud rate of 500 kbps, FD data phase baud rate of 10Mbps, and with differential probing established to observe the waveforms in a dominant-bit low format (L-H). This test basically shows if dominant and recessive bits have settled to valid/specified levels prior to receiver sampling, which typically occurs near the 60% sample point during the FD data phase. In other words, the CAN FD eye-diagram shows what the CAN receiver “sees” by synchronizing the scope’s acquisition and display timing to the CAN FD receiver’s timing. The result is a single measurement that provides insight into the overall signal integrity of the CAN FD physical layer network to show worst-case timing and worst-case vertical amplitude variations.

On the vertical axis, the eye-diagram display shows various peak-to-peak amplitudes. Variations in signal amplitudes on the differential CAN FD bus are primarily due to the following:

- System noise/interference/coupling
- Different transmitters (nodes in the system) exhibiting unique and different output characteristics
- Attenuated amplitudes due to network lengths and reflections

Although variations in peak-to-peak amplitudes can also be observed when viewing the bits and frames sequentially (non eye-diagram display), such as what is shown in Figure 3, the eye-diagram shows these variations – along with details of pulse shapes that may reveal termination problems – in a single overlaid picture.

On the horizontal axis, the eye-diagram display shows timing uncertainties primarily due to the following:

- Worst-case clock jitter
- Worst-case clock tolerance between various nodes in the system
- Bit-time quantization (typically 1/8th to 1/25th of 1 bit-time)

Worst-case timing errors such as these are extremely difficult to observe when viewed as a sequential waveform (non eye-diagram display).

## The Pass/Fail Mask

Overlaid and infinitely persisted bits of the eye-diagram are continually compared against a 6-point polygon-shaped pass/fail mask (gray zone), which is typical for most serial bus standards. The mask defines a failing region where signals are not supposed to enter. You can think of this region on the scope’s display as the “keep-out” zone. If captured waveforms enter this zone on this scope’s display, then the scope will display those portions of the waveform trace in red as shown in Figure 5. In addition, the scope will count the number of bits that fail the test, the total number of bits tested, and also provide failure rate statistics.

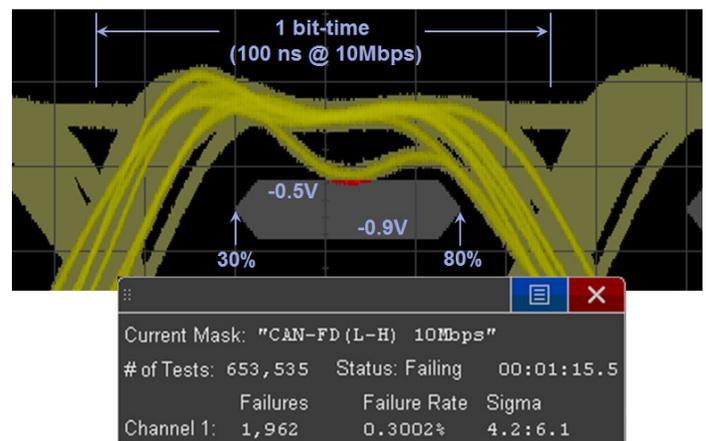


Figure 5: Pass/Fail mask for a CAN FD system running at 10Mbps in the data phase while probing to view dominant-bit low.

The mask shown in Figure 5 is based on a CAN FD system with a data phase rate of 10Mbps while probing the differential bus to view dominant-bit low. The top and bottom boundaries of the mask are based on specified worst-case CAN FD receiver threshold levels of -0.5 V to -0.9 V. If probing to view in a dominant-bit high format, Keysight also provides appropriate masks with the lower and upper levels of the mask set at +0.5 V to +0.9 V. The left side of the mask is positioned at the 30% bit-time point, while the right side of the mask is positioned at the 80% bit-time point.

In this particular CAN FD eye-diagram mask test, we can see that one of the system's nodes generates a recessive bit (high level) that rings and dips down into the failure zone near the top of this mask. Note that the portion of the waveform that violates the -0.5V threshold level is highlighted in red. This test reveals that there may be a risk that this "dip" in the differential signal could be interpreted by CAN FD transceivers as a dominant bit. We can also see that this CAN FD system generates approximately 20 ns of peak-to-peak timing jitter over the worst-case 10 bit-times that are tested. And finally, the mask test statistics window shows us that the failure rate for this test was approximately 0.3% based on testing more than 650,000 bits over a 75 seconds test time.

The apex points of the polygon mask can be edited using most any common ASCII-based text editor such as Windows NotePad, and then saved with a .msk extension. For custom CAN FD mask files, contact Keysight Technologies for support.

## Summary

Although CAN FD serial bus protocol analyzers can provide higher application-level data transfer information on the CAN bus, they reveal little or nothing about the signal integrity of individual bits that may be inducing errors in the system. This is why engineers and technicians often use oscilloscopes with CAN FD trigger and decode capability to test the physical layer characteristics of the differential CAN FD network. And the single most important measurement that can be performed with an oscilloscope to evaluate the overall quality of the physical layer in one composite measurement is a CAN FD eye-diagram mask test. Creating a proper CAN FD eye-diagram measurement on a scope's display requires much more than just triggering on rising and/or falling edges. It requires a special triggering and display clock recovery algorithm that emulates worst-case re-synchronization of CAN FD receivers to capture and overlay up to the worst-case 10th bit-time after re-synchronization (two consecutive stuffed bits).

Not only can Keysight's InfiniiVision X-Series oscilloscopes trigger, decode, and perform eye-diagram mask test measurements on differential CAN and CAN FD bus signals, but these oscilloscopes can also perform analysis on other serial bus standards often found in automotive applications including LIN, SENT, FlexRay, I<sup>2</sup>C, SPI, RS-232/UART, and USB.

## System Requirements

In addition to the Keysight N2818A differential active probe (or equivalent) to probe the differential bus, performing CAN FD eye-diagram mask tests requires that your Keysight InfiniiVision 3000T or 4000 X-Series oscilloscopes be licensed with the DSOXT3AUTO or DSOX4AUTO serial trigger and decode option (CAN, CAN FD, & LIN), as well as the DSOX3MASK or DSOX4MASK mask test option. Also available are the DSOXT3APPBNDL and DSOX4APPBNDL application bundle options that includes all the scope's available options (CAN, CAN FD, LIN, SENT, FlexRay, I<sup>2</sup>C, SPI, Mask, etc.) at a significantly reduced price.

In addition to the above listed minimum system requirements, your 3000T or 4000 X-Series oscilloscope must have firmware version 4.05 or greater to support CAN FD eye-diagram mask testing.

## Related Literature

Publication Title	Publication Type	Publication Number
InfiniiVision 3000T X-Series Oscilloscopes	Data sheet	5992-0140EN
InfiniiVision 4000 X-Series Oscilloscopes	Data sheet	5990-1103EN
Serial Bus Options for InfiniiVision X-Series Oscilloscopes	Data sheet	5990-6677EN
InfiniiVision Oscilloscope Probes & Accessories	Data sheet	5968-8153EN
Oscilloscope Measurement Tools to Help Debug Automotive Serial Buses Faster	Application note	5991-0512EN
CAN 2.0 Eye-diagram Mask Testing	Application note	5991-0484EN
Debug Automotive Designs Faster with CAN-dbc Symbolic Trigger and Decode	Application note	5991-2847EN
Characterizing CAN Bus Arbitration using an InfiniiVision X-Series Oscilloscope	Application note	5991-4166EN
Using Segmented Memory for Serial Bus Applications	Application note	5990-5817EN

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