Using an Agilent 6000 Series MSO To Debug an Automotive CAN Bus

Application Note 1576

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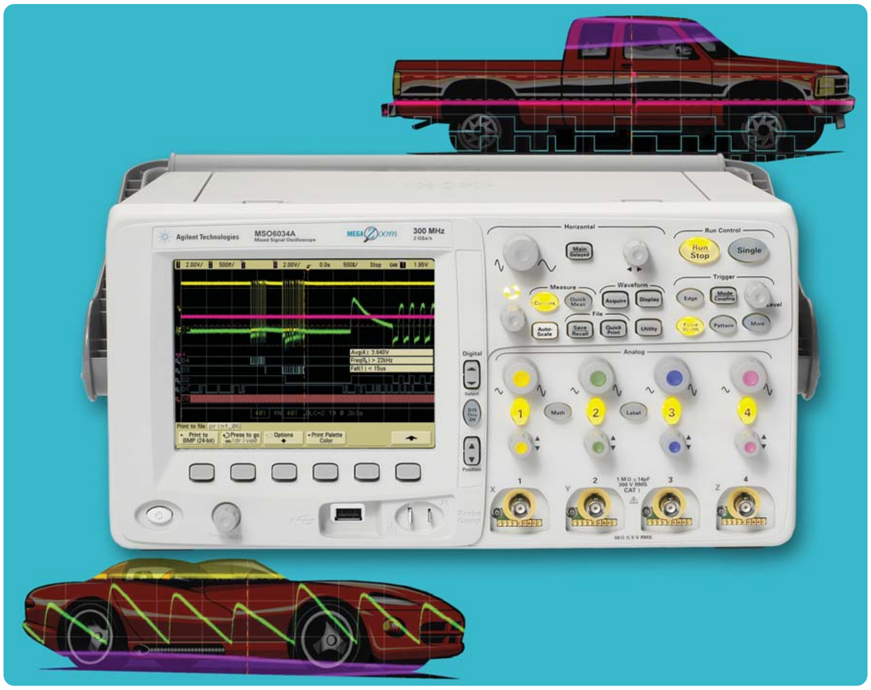

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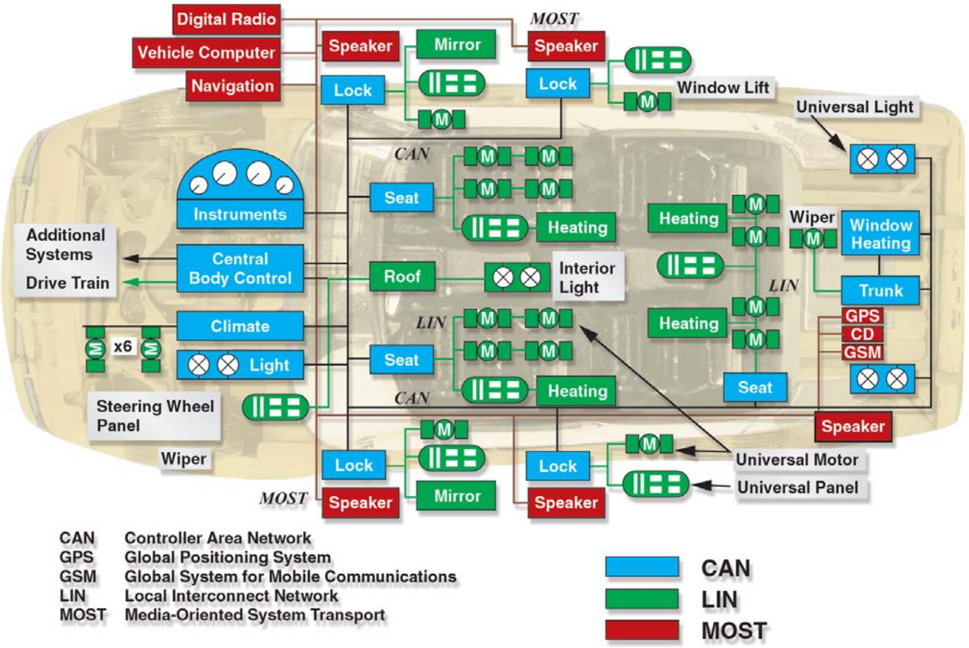
Introduction

To improve efficiency of system communication and to reduce cost, all of today’s automotive designs employ a variety of serial bus communication protocols. The I^2C and SPI protocols are most often used for chip-to-chip communication within electronic control units (ECUs). For long-haul serial communication between various automotive subsystems such as anti-lock breaks, airbag deployment, engine control, and GPS navigation, the CAN, LIN, and MOST protocols are the most popular serial buses implemented in today’s vehicles, as shown in Figure 1. Unfortunately, long-haul communication is often susceptible to signal integrity problems caused by the naturally harsh environment found in automobiles, including signal interference from ignition systems and random system noise, which can sometimes create errors during critical communication cycles.

By definition, automotive electronic systems are embedded mixed-signal systems because they feature multiple analog sensors and analog motor controls under digital control. For years, traditional oscilloscopes have been the primary tool-of-choice among automotive electronic system design engineers to measure the quality of both analog and digital signals. But traditional analog and digital oscilloscopes have many limitations, including lack of complex serial triggering and limited input channels of acquisition. However, a new class of measurement tools called mixed signal oscilloscopes (MSOs) offers many advantages for debugging and verifying proper operation of today’s automotive designs.

To illustrate the unique advantages of Agilent 6000 series MSOs, this application note shows a typical debugging methodology designed to uncover signal integrity problems in a CAN-based automotive system. While synchronizing on and capturing a CAN differential signal that digitally transmits analog sensor data to an ECU, the MSO was also used to repetitively capture and measure the output amplitude of a remote analog input sensor. At the same time, the MSO also was used to capture multiple SPI control signals within the ECU. But before we explore this particular automotive CAN design and explaining how the MSO was used to debug and discover a signal integrity problem, let's first define what we mean by "MSO."

Figure 1:
Typical distributed automotive electronic system under serial bus control



CAN	Controller Area Network
GPS	Global Positioning System
GSM	Global System for Mobile Communications
LIN	Local Interconnect Network
MOST	Media-Oriented System Transport

What is an MSO?

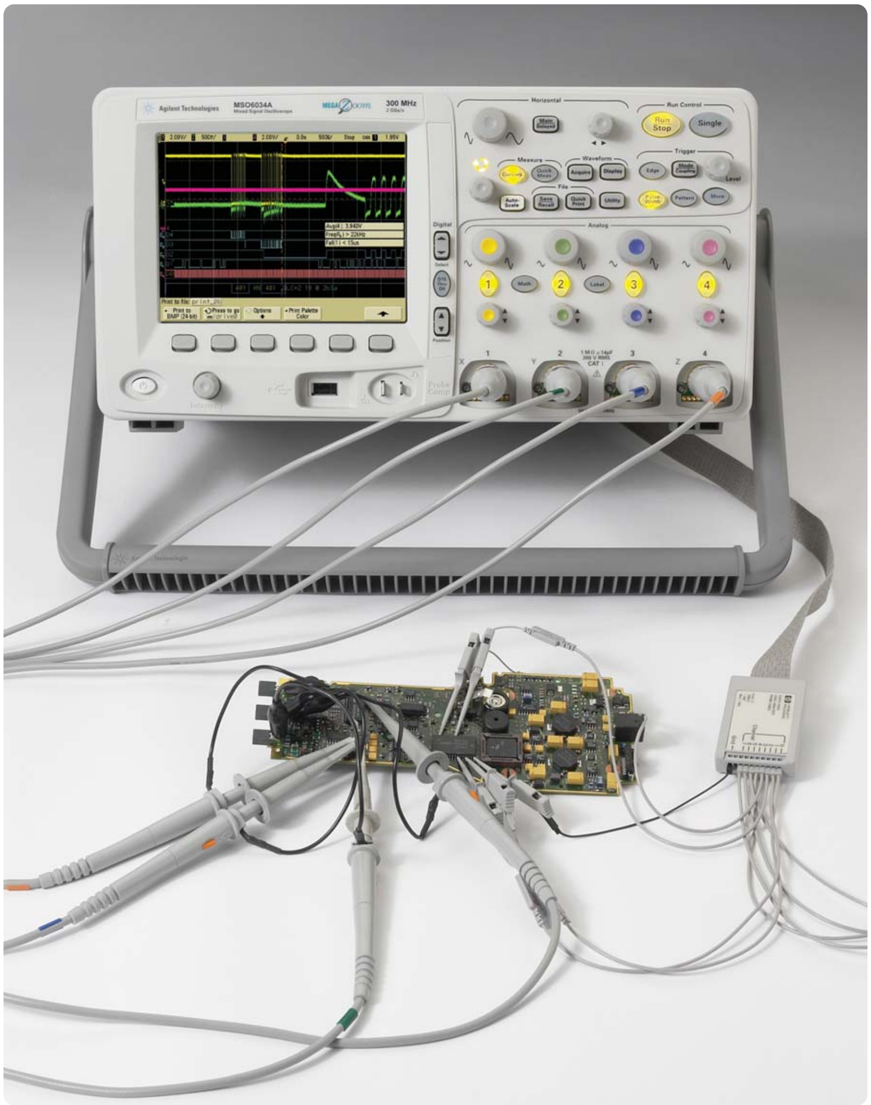


Figure 2: Agilent's 6000 Series mixed signal oscilloscope (MSO)

An MSO is a hybrid test instrument that combines all of the measurement capabilities of a digital storage oscilloscope (DSO) with some of the measurement capabilities of a logic analyzer, along with some serial protocol analysis — into a single, synergistic instrument. With an MSO, you are able to see multiple time-aligned analog, parallel-digital, and serially decoded waveforms on the same display, as shown in Figure 2. Although many of today's traditional oscilloscopes have limited triggering capabilities, some of today's MSOs include sophisticated serial triggering and protocol decode analysis that are optimized for automotive electronic system debug.

MSOs typically lack the large number of digital acquisition channels of full-fledged logic analyzers and also lack the higher abstraction levels of analysis provided by serial protocol analyzers. But the relative simplicity of MSOs allows you to use them with ease and avoid the complexities involved in operating logic analyzers and protocol analyzers. In fact, one of the primary advantages of an MSO is its use model. You use an MSO in much the same way you use an oscilloscope. And because MSOs are highly integrated, they are much easier to use than loosely tethered two-box mixed-signal measurement solutions consisting of either a scope linked to a logic analyzer or a scope linked to a serial bus protocol analyzer. A good MSO, such as Agilent's MSO6000, is user-friendly, provides fast waveform update rates, includes serial triggering and analysis, and operates much like an oscilloscope — not like a logic analyzer or protocol analyzer.

Verifying proper operation of an automatic windshield-wiper system

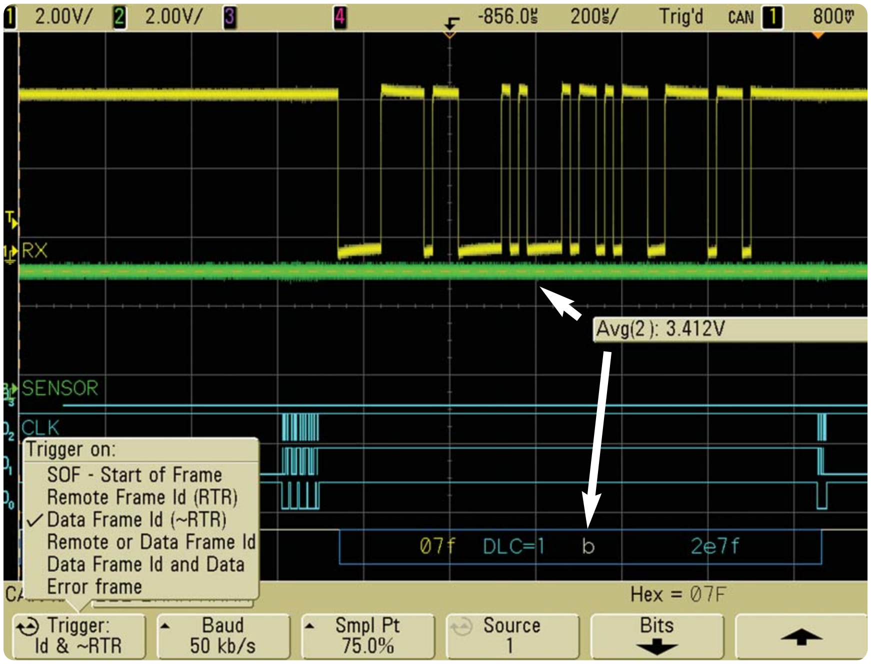


Figure 3: Capturing multiple SPI and CAN signals using an MSO with CAN triggering and decode

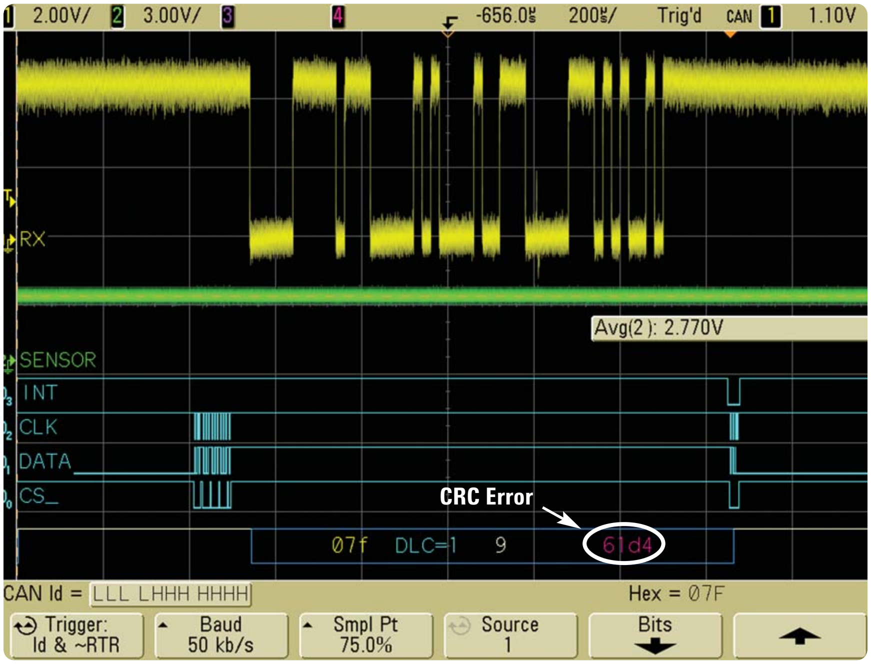
Before integrating a new embedded design into an automobile, an Agilent MSO was first used in the lab environment to verify proper circuit and protocol operation of a prototype automatic windshield-wiper system. Figure 3 shows multiple time-correlated analog and digital signals from the prototype system captured and displayed on an MSO6104A. The channel-1 waveform (top/yellow trace) is the differential CAN bus signal that communicates to various remote subsystems including the windshield-wiper system. The channel-2 waveform (middle/green trace) shows the analog output signal level of a remote rain sensor that optically detects the amount of rain/snow striking the windshield. Also shown are various time-correlated SPI control signals (blue traces shown near the bottom of the scope's display) within the ECU including CLOCK, DATA, CS, and an INTERRUPT signal — all captured using some of the MSO's available sixteen logic-timing channels. The multi-colored bus trace at the bottom of this oscilloscope's display shows time-correlated decoded information of CAN packets captured on a user-selected CAN acquisition channel, which in this case was channel-1.

In this particular design, the instantaneous output amplitude of the remote analog sensor is converted to a digital value using an analog-to-digital converter (ADC), and then it is serially transmitted to the ECU as a single data byte within a particular data frame ($07F_{HEX}$). To capture repetitive transmissions of this sensor's output and verify proper operation of the prototype, the MSO was initially set up to trigger on the CAN data frame $07F_{HEX}$, as shown in Figure 3. The analog sensor's output value is always transmitted in this frame. With this oscilloscope setup condition, the automotive design engineer was able to easily measure the analog amplitude of the sensor's output (3.41 V) while monitoring and verifying the data value (B_{HEX}) that was actually transmitted within the CAN packet. While testing this prototype automatic wiper system in the lab, no problems were observed, and the CAN differential signal appears to be nearly noise-free.

Unfortunately, when this automotive subsystem was integrated into the automobile, the automatic wiper system performed unreliably, and it was determined that the data value received by the ECU did not always match the real-world physical condition of the analog moisture sensor. When circuit problems are predictable and repetitive, it can be a fairly easy task to isolate and track down the root cause of a circuit problem. But in this particular automotive design, once the design was integrated into the automobile, errant transmissions of data from the sensor were random and infrequent — making it difficult to isolate the cause of the problem.

Hardware-accelerated CAN decode reveals an infrequent problem

Figure 4 shows the same signals that were originally measured in the lab, but this time the signals were captured with the automatic wiper system integrated into the automobile. We now see the influence of noise and interference on the differential CAN signal caused by the harsh environment in the vehicle. The automotive design engineer monitored the scope's display while repetitively triggering on data frame ID: 07F$_{HEX}$. The engineer observed an occasional red "flash" within the CAN decode string (bottom trace), as shown in Figure 4. This MSO's CAN decode feature color-coded bad CRCs in red, and other frame error conditions are shown as a red bus trace. This scope's very fast waveform update rate (up to 100,000 real-time waveforms per second) and hardware-accelerated serial decode were critical to capturing the infrequent bad data transmissions. The hardware-accelerated serial decode displays decoded strings as fast as 60 updates per second – faster than the human eye can read, but slow enough to see color-coded error conditions if they occur infrequently.



CRC Error

CAN Id = LLL LHHH HHHH

Hex = 07F

Trigger: Id & ~RTR

Baud 50 kb/s

Smpl Pt 75.0%

Source 1

Figure 4: Random errors observed in CAN decode while triggering on data frame ID: 07F$_{HEX}$

Most oscilloscopes with deep memory and serial decode capabilities update very slowly. This is primarily because deep memory records are decoded using software post-processing techniques. Waveform and decode updates can sometimes take seconds. This means that if errors occur infrequently, most error conditions will randomly occur during the scope's dead-time – not during the scope's acquisition time. This makes it nearly impossible to randomly capture an errant transmission with a traditional oscilloscope, even with CAN triggering and decode capabilities. But hardware-accelerated CAN decoding in the Agilent 6000 series MSO statistically enhanced the probability of catching random and infrequent error conditions, since both the waveform and CAN decode update rates exceeded the repetitive rate of occurrences of data frame 07F$_{HEX}$.

To freeze the scope's display on just one occurrence of a "bad" data transmission, the design engineer first attempted to quickly press the scope's front-panel STOP key when a "red" decode string was observed. Unfortunately, the scope's waveform and decode update rate was so fast that by the time the STOP key was pressed, several subsequent acquisitions had occurred and the display always stopped on a "good" data transmission.

Triggering the MSO on error frames reveals a signal-integrity problem

The next step was to setup the scope's triggering to synchronize only on error frames, as shown in Figure 5. With this trigger setup condition (trigger on error frame), the scope only captured and displayed "bad" CAN transmissions and ignored "good" transmissions. Now the engineer could either press the STOP key at any time to analyze the signal quality of the last "bad" transmitted CAN frame, or use the scope's single-shot acquisition mode to freeze the scope's display on the next "bad" data transmission. From this display (Figure 5), the engineer's first suspicion was that perhaps the random data transmission problems were due to excessive random noise that was coupling into the differential CAN signal (top/yellow trace). We can see that the noise riding on the CAN signal appears to have a Gaussian distribution as evidenced by the 256 levels of display intensity provided by this scope's MegaZoom III technology display system — similar to the display quality of a traditional analog oscilloscope. But after measuring the random noise level with the MSO's "standard-deviation" measurement, the engineer determined that the signal noise level was within specified tolerances and not inducing errors.

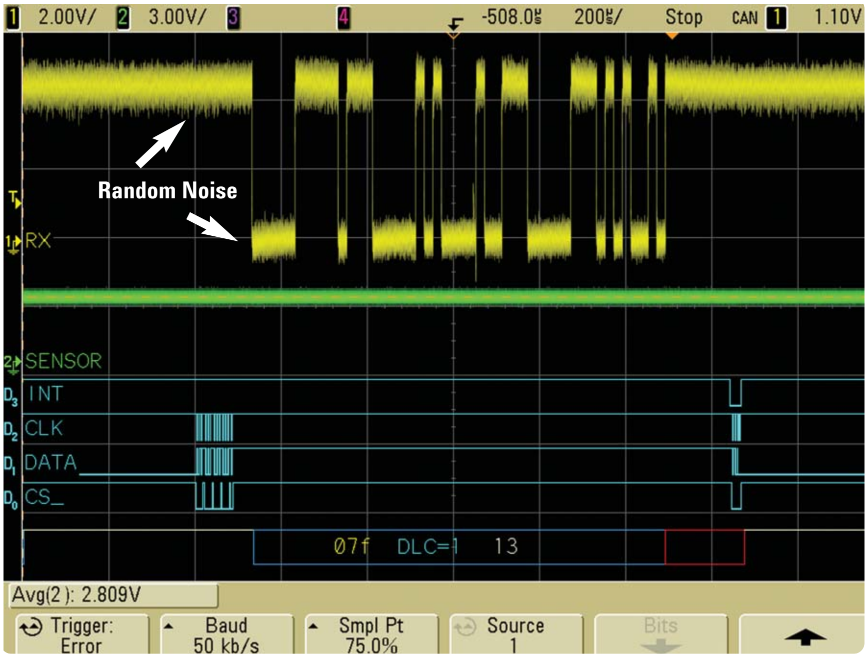


Figure 5: Triggering on CAN error frames isolates acquisitions on bad frame transmissions

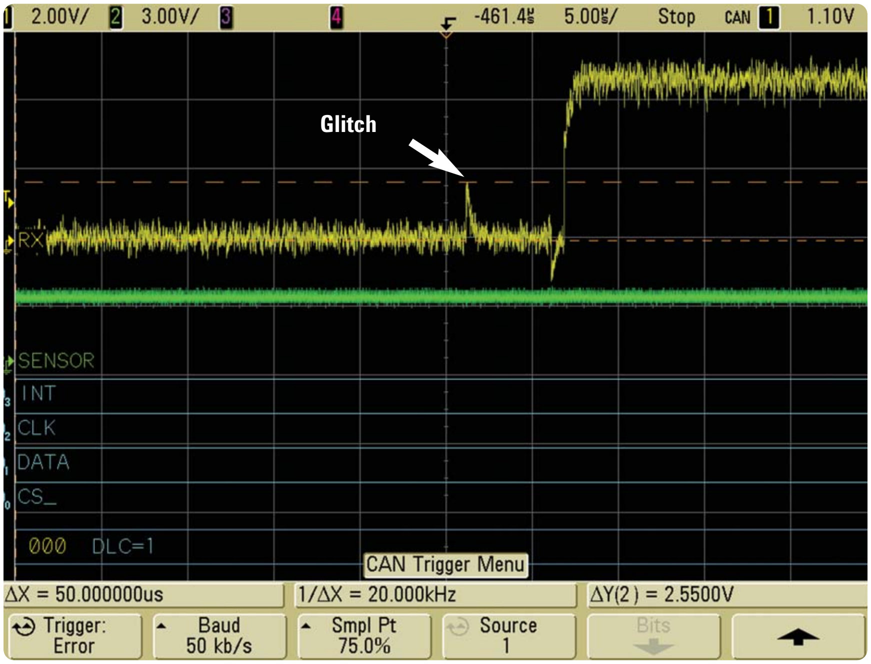


Figure 6: Zooming in on differential CAN waveform reveals a glitch

After further inspection of the differential CAN signal on channel-1, the engineer discovered that a narrow glitch had occurred during this frame’s data transmission just prior to the 5th rising edge of the differential CAN signal. When viewing this stored CAN frame in the normal “compressed” mode of a deep-memory acquisition (up to 8 M points) spread across the scope’s display with the main timebase at 200 µs/div, this narrow glitch was barely visible and could be easily missed, as shown in Figure 5. But when the engineer expanded the timebase on the stored trace to 5 µs/div (Figure 6), the glitch was easily viewed with this scope’s high sample rate resolution (up to 4 GSa/s).

After discovering this glitch and measuring its amplitude with the MSO’s cursors, the engineer pressed the scope’s front-panel RUN key again to begin repetitive acquisitions while triggering only on error frames. While observing the scope’s repetitive waveform updates, the engineer could then see that narrow glitches were occurring not only infrequently, but also at random locations within the data frame and with no particular phase relationship to the differential CAN signal. It appeared that these glitches were being caused by signal coupling from a non-phase-related source. If the source of these glitches could be tracked down, then the root cause could more easily be determined and fixed.

Triggering the MSO on the random glitch reveals the source of the problem

To synchronize the scope's display on the non-phase-related glitch rather than error frames, the automotive design engineer next set up the scope to uniquely trigger on the glitch. This was accomplished by using the scope's pulse-width triggering capability which can be defined to trigger on either positive or negative pulses based on a user-specified range of time (pulse-width). In this case, the engineer configured the scope to only trigger acquisitions on positive pulses of the channel-1 input (differential CAN signal) if the width of the pulse was < 500 ns. With this setup condition, the scope synchronized its display on the randomly occurring glitch, always capturing and showing the glitch near the scope's default center-screen trigger location. Now the CAN data frames appeared uncorrelated in terms of phase relationship relative to the glitch trigger source.

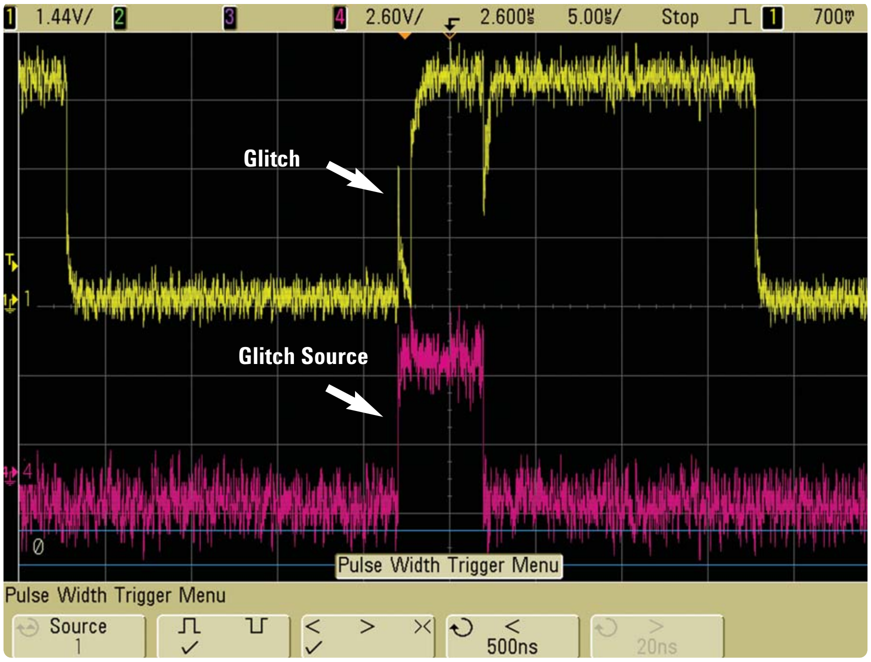


Figure 7: Pulse-width triggering reveals source of random and infrequent glitch

To track down the source of this glitch, the engineer then connected another probe to an unused channel (channel-4) of this 4+16-channel MSO and began probing "suspect" signals in the automobile to see which signal might be synchronized/phase-related to the glitch. After a few minutes, the engineer found the source of the glitch, as shown in Figure 7. The channel-4 waveform (bottom pink trace) shows a digital pulse that controlled a relay that triggered a high-voltage surge within the vehicle's voltage regulator. If the voltage regulator cycled during the transmission time of data frame ID: $07F_{HEX}$, an error would occasionally occur in the windshield-wiper system. Once the engineer tracked down the source of the problem, it was fairly easy to isolate the windshield-wiper CAN node from the high-voltage surge signal with better shielding, which also significantly improved this CAN system's noise-immunity.

Summary

This paper showed how an Agilent 6000 series mixed signal oscilloscope (MSO) can be used to more effectively and efficiently turn-on and debug an embedded mixed-signal design in an automobile that utilizes serial bus CAN data transmission. Critical characteristics of the MSO that enabled the automotive design engineer to quickly discover the cause of the intermittent problem included multiple channels of time-correlated analog and logic acquisition, fast waveform update rates, hardware-accelerated CAN bus decode, and various triggering capabilities including frame ID, error frame, and glitch/pulse-width triggering. Although this application note focused on an automatic windshield-wiper application, the debugging techniques described in this paper can also be directly applied to other automotive applications. The next time you need to turn-on and debug your embedded automotive mixed-signal design, you might consider using an Agilent 6000 series MSO in place of your current DSO, protocol analyzer, and/or logic analyzer measurement solution.

Glossary

ADC	Analog-to-Digital Converter, sometimes referred to as an A-to-D
CAN	Controller Area Network is a differential 2-wire interface with data rates ranging from 10kbps to 1Mbps. Multiple applications include window & seat controls, engine management, and anti-skid systems.
DSO	Digital Storage Oscilloscope that acquires and displays analog characteristics of input signals using either real-time or equivalent-time sampling techniques
ECU	Electronic Control Unit is an embedded computer system found in automobiles
I^2C	Inter-integrated Circuit bus is a common 2-wire serial bus that utilizes a self-arbitration protocol and is often used for chip-to-chip communication
LIN	Local Interconnect Network is a class A protocol operating up to 19.2kbps over a cable length up to 40 meters. Typical applications include window controls and other non-time/safety-sensitive functions such as comfort controls.
MOST	Media Oriented Systems Transport bus provides an optical solution for automotive media (entertainment) networks such as video, CD, etc.
MegaZoom III technology	An Agilent proprietary acquisition and display technology that provides a digital storage oscilloscope with extremely fast waveform update rates (> 100,000 real-time waveforms per second) and a high-resolution display quality that meets or exceeds the display quality of traditional analog oscilloscopes
MSO	Mixed Signal Oscilloscope that synergistically combines all of the measurement capabilities of an oscilloscope with some of the measurement capabilities of a logic analyzer and includes a time-correlated display of both analog and digital waveforms
SPI	The Serial Peripheral Interface bus is a 4-wire serial communications interface used by many microprocessor peripheral chips. The SPI circuit is a synchronous serial data link that provides support for a low/medium bandwidth (1 megabaud) network connection amongst CPUs and other devices supporting the SPI.

Related Agilent literature

Publication Title	Publication Type	Publication Number
Agilent 6000 Series Oscilloscopes	Data sheet	5989-2000EN
Agilent 6000 Series Oscilloscope Probes and Accessories	Data sheet	5968-8153EN
Why Oscilloscope Waveform Update Rates are Important	Application note	5989-2002EN
Debugging Embedded Mixed-Signal Designs Using Mixed Signal Oscilloscopes	Application note	5989-3702EN
Oscilloscope Display Quality Impacts Ability to Uncover Signal Anomalies – Agilent 6000 series versus Tek TDS3000B series oscilloscope	Application note	5989-2003EN
Oscilloscope Display Quality Impacts Ability to Uncover Signal Anomalies – Agilent 6000 series versus LeCroy WaveSurfer 400 series oscilloscope	Application note	5989-2004EN
Deep Memory Oscilloscopes: The New Tools of Choice	Application note	5988-9106EN
Evaluating Oscilloscope Vertical Noise Characteristics	Application note	5989-3020EN
Ten Things to Considers When Selecting Your Next Oscilloscope	Application note	5989-0552EN

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