Technical White Paper

How Signal Improvement Capability Unlocks the Real Potential of CAN-FD Transceivers

Vikas Kumar Thawani

ABSTRACT

Modern-day automobiles perform a plethora of functions to improve vehicle safety, performance and comfort. From powertrain to advanced driver assistance systems, from body electronics and lighting to infotainment and safety, a large number of electronic control units (ECUs) deployed in vehicles perform these electromechanical functions.

ECUs exchange control and data-log information through in-vehicle network buses. Among Controller Area Network (CAN), Local Interconnect Network (LIN), FlexRay and Ethernet, the CAN bus remains the most popular choice given its ease of use, good common-mode noise rejection, priority-based messaging, bitwise arbitration to handle bus contention, and error detection and recovery.

The ease at which it is possible to scale up a vehicle network by adding nodes to an existing CAN bus is also a major advantage. This advantage diminishes, however, when networks become complex, such as a star topology connection of CAN nodes. Reflections caused by the unterminated stubs inherently present in these networks can cause faulty signal communication at higher speeds. Therefore, CAN-Flexible Data Rate (FD) transceivers, although rated for 5 Mbps, have to be used at less than 2 Mbps in actual vehicle networks. Signal improvement capability (SIC) enables the use of CAN-FD transceivers at 5 Mbps and beyond for complex star networks without requiring major redesigns.

Table of Contents

List of Figures

List of Tables

Trademarks

All trademarks are the property of their respective owners.

1 What is SIC?

Signal improvement is an additional capability added to CAN-FD transceivers that enhances the maximum data rate achievable in complex star topologies by minimizing signal ringing. CAN SIC transceivers need to meet or exceed the specifications of the International Organization for Standardization (ISO) 11898-2:2016 high-speed CAN physical layer standard and the CAN-in-Automation (CiA) 601-4 signal improvement specification.

Figure 1-1 shows a regular CAN-FD transceiver where the CAN bus signal rings above 900 mV (the dominant threshold of a CAN receiver) and below 500 mV (the recessive threshold of a CAN receiver), resulting in receive data (RXD) glitches. With reference to CiA 601-4, Figure 1-2 shows how a CAN SIC capability transceiver attenuates bus signal ringing, resulting in the correct RXD signal.

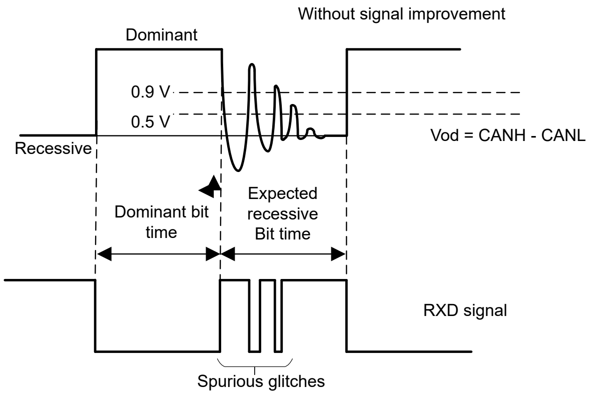

Figure 1-1. CAN Bus and RXD Waveforms Without SIC

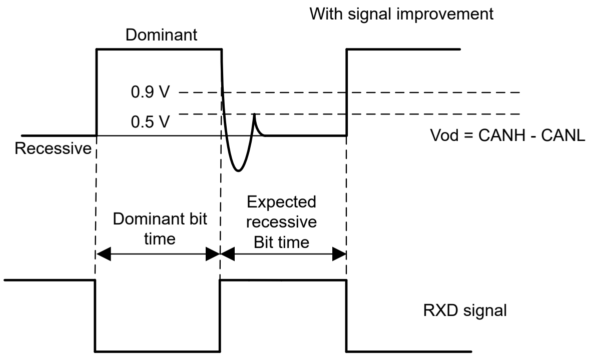

Figure 1-2. CAN Bus and RXD Waveforms With SIC

In terms of electrical parameters, a CiA 601-4-compliant CAN SIC transceiver has a much tighter bit-timing symmetry and loop-delay specification compared to a regular CAN-FD transceiver, as shown in Table 1-1. The segregation of delays of transmit and receive paths can help system designers clearly calculate network propagation delay in the presence of other signal chain components. One thing to note is that the timing specified in CiA 601-4 is data rate-agnostic and holds true for both 2- and 5-Mbps operation.

Table 1-1. Comparing the CiA 601-4 and ISO 11898-2 Timing Specifications

		CiA 601-4 Specifications		ISO 11898-2:2016 Specifications	
Parameter	**Notation**	**Min [ns]**	**Max [ns]**	**Min [ns]**	**Max [ns]**
Signal improvement time TX-based	$t_{SIC\_TX\_base}$	N/A	530	N/A	
Transmitted bit -width variation	$\Delta t_{Bit(Bus)}$	–10	10	–65 for 2 Mbps –45 for 5 Mbps	30 for 2 Mbps 10 for 5 Mbps
Received bit width	$\Delta t_{Bit(RxD)}$	–30	20	–100 for 2 Mbps –80 for 5 Mbps	50 for 2 Mbps 20 for 5 Mbps
Receiver timing symmetry	Δt_{REC}	–20	15	–65 for 2 Mbps –45 for 5 Mbps	40 for 2 Mbps 15 for 5 Mbps
Propagation delay from transmitter data (TXD) to bus dominant	$t_{prop(TxD\text{-}busdom)}$		80	Only loop delay, TXD to bus to RXD, is specified at 255 ns max	
Propagation delay from TXD to bus recessive	$t_{prop(TxD\text{-}busrec)}$		80		
Propagation delay from bus to RXD dominant	$t_{prop(busdom\text{-}RxD)}$		110		
Propagation delay from bus to RXD recessive	$t_{prop(busrec\text{-}RxD)}$		110		

2 The Limitations of Classical CAN and Regular CAN-FD

The first-generation CAN protocol, ISO 11898-2, also known as Classical CAN, was released around 1993. The protocol allowed only 8 bytes of payload data transfer, and a maximum specified data rate of 1 Mbps. These limitations were quickly realized in automotive applications, where vehicles have a number of electronic nodes that communicate with each other using the CAN bus.

The CAN-FD protocol specification was released around 2015, which increased the payload length to 64 bytes and the maximum signaling rate in the data phase to 5 Mbps. The arbitration phase signaling rate was still limited to 1 Mbps, however, for backwards compatibility with Classical CAN.

While CAN-FD brought the advantages of a faster data rate and a longer payload, it wasn't sufficient to keep pace with the ever-increasing number of ECUs added to vehicle CAN bus networks. Designers realized that they could not harness the real potential of CAN-FD transceivers, as bus ringing resulting from complex star networks affected correct signal communication. Figure 2-1 is an example star topology.

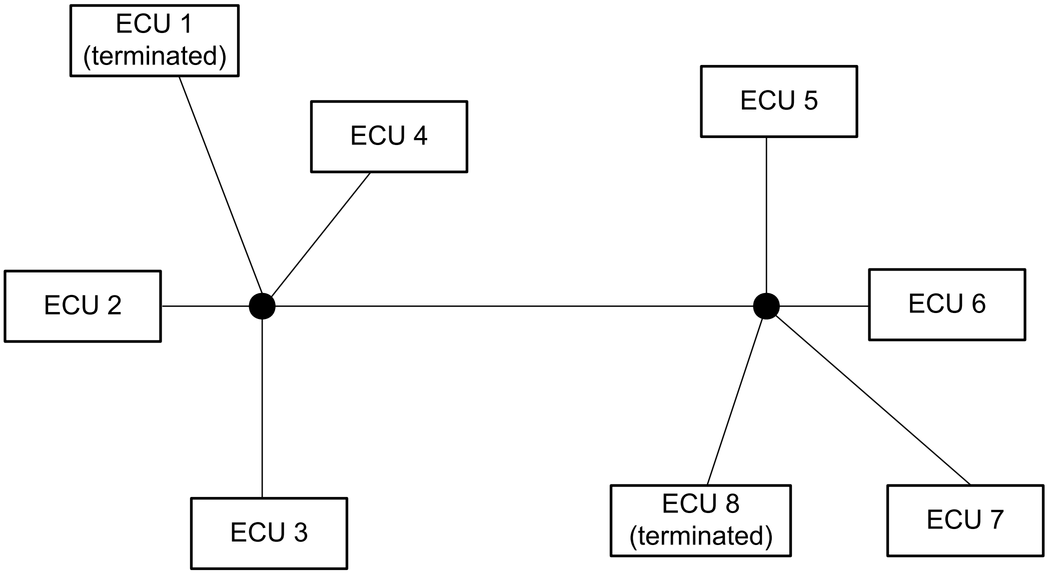

Figure 2-1. CAN Nodes Connected in a Star Network

In complex star topologies with multiple stubs, a signal traveling on the bus experiences impedance mismatch which causes reflections. These reflections distort the CAN bus and cause it to oscillate, resulting in an incorrect CAN bus level and RXD at the sampling point. Although these network effects were not specific to CAN-FD networks, at the lower-speed operation of Classical CAN the bit duration was longer, and the bus ringing diminished such that it was possible to sample the correct bit, as shown in Figure 2-2, resulting in correct communication.

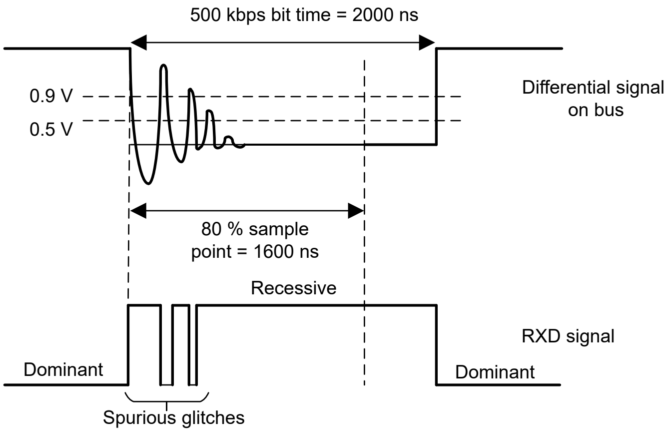

Figure 2-2. CAN Bus Ringing and RXD Glitch for Classical CAN Speeds

For 5-Mbps CAN-FD operation, a 200-ns bit duration was much too small for the ringing in complex star topologies to disappear, hampering reliable data communication. This deterred system designers from using CAN-FD at 5 Mbps.

With an increase in the exchange of network data and faster throughput demands in modern-day vehicles, CAN SIC paves the way for a next-generation in-vehicle communication bus technology that is faster and provides more network flexibility and scalability.

3 How CAN SIC Reduces Bus Ringing

The CAN bus has two logical states during normal operation: recessive and dominant, as shown in Figure 3-1.

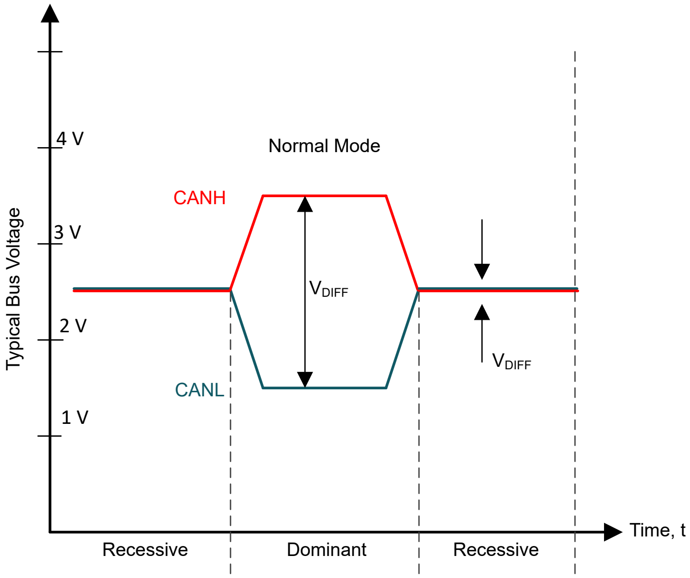

Figure 3-1. CAN Bus Voltage Levels

A dominant bus state occurs when driving the bus differentially and corresponds to a logic low on the TXD and RXD pins. A recessive bus state occurs when the bus is biased to $V_{CC}/2$ through the high-value internal input resistors (R_{IN}) of the receiver and corresponds to a logic high on the TXD and RXD pins. A dominant state overwrites the recessive state during arbitration. The recessive-to-dominant signal edge on the CAN bus is usually clean, as it is strongly driven by the transmitter. The differential transmitter output impedance of the CAN transceiver during the dominant phase is approximately 50 Ω and closely matches the network characteristic impedance. For a regular CAN-FD transceiver, the dominant-to-recessive edge is when the driver differential output impedance suddenly goes to approximately 60 kΩ, and the signal reflected back experiences an impedance mismatch, which causes ringing.

Transmitter-based SIC detects the dominant-to-recessive edge on TXD and activates ringing suppression circuitry on the driver output. The CAN driver continues driving the bus recessive strongly until $t_{SIC\_TX\_base}$ so that reflections diminish and the recessive bit is clean at the sampling point. In this active recessive phase, the transmitter output impedance is low (approximately 100 Ω). Since the reflected signal does not see a huge impedance mismatch, ringing is attenuated considerably. After this phase ends and the device enters a passive recessive phase, the driver output impedance rises to approximately 60 kΩ. Figure 3-2 shows this phenomenon.

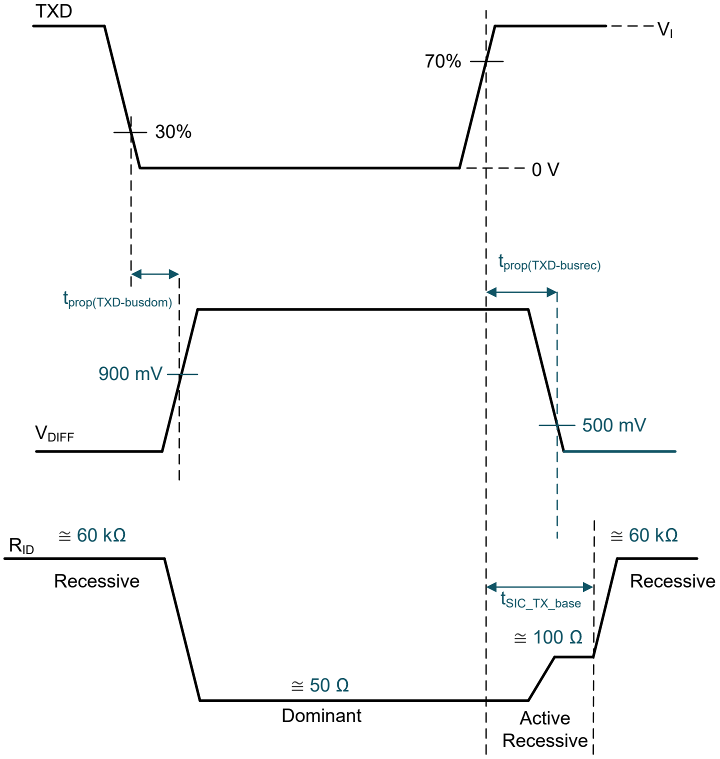

Figure 3-2. CAN SIC Technology: Sequence of Events

An important factor in the active recessive phase strongly driving the bus is that it should only last for a maximum of 530 ns ($t_{SIC\_TX\_base}$, as listed in Table 1-1). The data phase of the CAN-FD protocol only lasts for 200 ns max (if operated at 5 Mbps), so this ringing suppression will be active for the entire recessive bit duration, resulting in correct CAN bus and RXD signals. For the arbitration phase, however – where the fastest bit duration is 1 µs for 1-Mbps operation, multiple transmitters can transmit simultaneously, and the dominant bit has to overwrite the recessive bit – the duration of ringing suppression may place some limits on the overall network length and arbitration speed. See the CiA 601-4 specification for more details.

4 Experimental Results on TI's TCAN1462 Device

To showcase the ringing-suppression functionality of the Texas Instruments (TI) eight-pin TCAN1462 CAN SIC transceiver, Texas Instruments conducted an experiment with the following setup:

- Two-node point-to-point communication, where node 1 is the TCAN1462 and node 2 is the TCAN1044A, a regular CAN-FD transceiver, as shown in Figure 4-1. The ringing network (specified by CiA 601-4) emulating a complex star topology is connected across the CAN bus terminals. As the waveforms in Figure 4-2 and Figure 4-3 show, the CAN bus and RXD signals look clean when the TCAN1462 is driving. But when the TCAN1044A is driving, there is considerable ringing on the bus and RXD glitches.

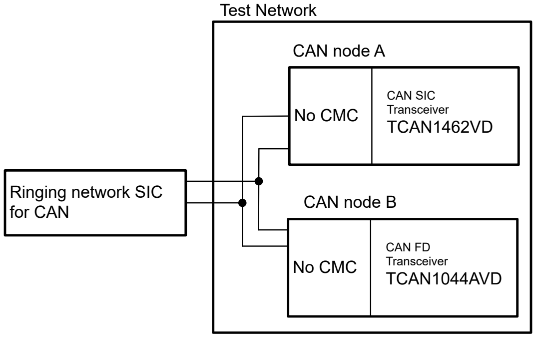

Figure 4-1. Network with Two Node and Ringing Circuit

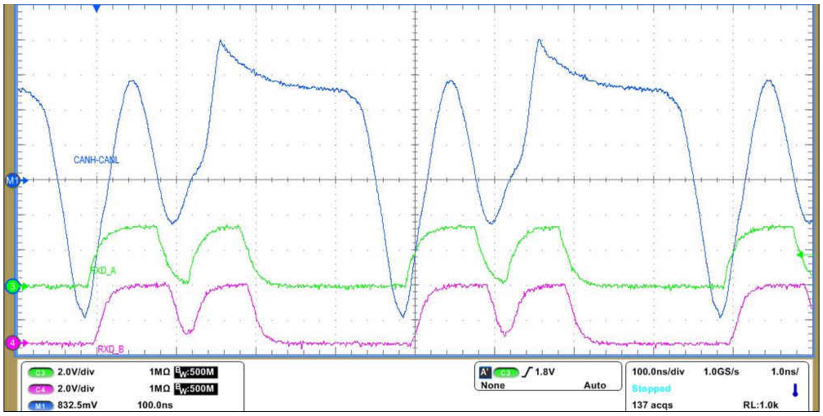

Figure 4-2. Waveforms with CAN-FD Driving the Network

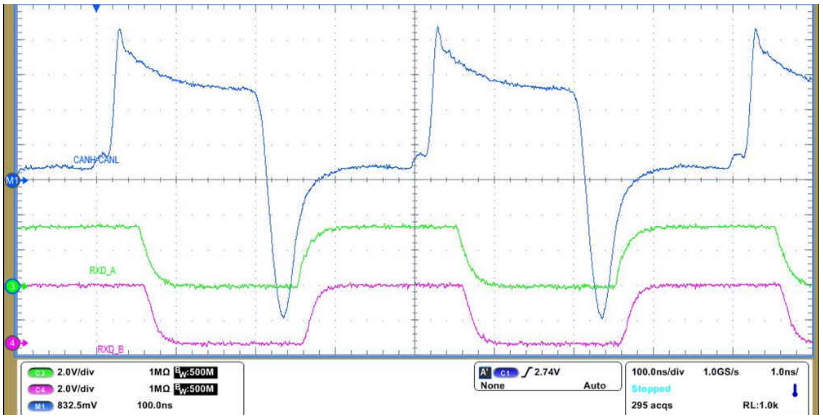

Figure 4-3. Waveforms with CAN SIC Driving the Network

The hugely negative-going V_{OD} is not a problem and there is no overshoot on V_{OD}, resulting in clean RXD.

5 TI's CAN SIC Devices

TI has released two CAN SIC devices: the eight-pin TCAN1462 with standby mode support, which is pin-to-pin compatible with traditional eight-pin CAN transceivers; and the 14-pin TCAN1463 with sleep mode and a WAKE/INH capability, which is pin-to-pin compatible with traditional 14-pin CAN transceivers.

The TCAN1462 is available in two variants: the TCAN1462 for 5-V bus/logic levels and the TCAN1462V with 1.8- to 5-V logic-level support. These devices have major benefits compared to competing devices in the market, as shown in Table 5-1.

Table 5-1. The TCAN1462 Compared to it's Nearest Competing Device

Parameter	Competing Device	TCAN1462	End System Implication
V_{io} (logic supply) range	3 V to 5.5 V	1.71 V to 5.5 V	TI is future ready for 1.8-V logic I/O support
SIC timing	Only meets with ±5% V_{CC}	With ±10% V_{CC}	TI does not need a tightly regulated supply to meet important SIC parameters required by standard
Minimum V_{od} of 1.5 V	Only meets with ±5% V_{CC}	With ±10% V_{CC}	
Bus fault protection	–36 V to 40 V	±58 V	A high bus fault means more resistant to faults. Also, TI supports bus faults for 24-V systems, enabling reuse across platforms
Electrostatic discharge (ESD) on bus pins	6 kV	±8 kV	Higher ESD protection
Small outline transistor-23 package	No	Yes	TI offers a smaller footprint package option

6 Benefits of CAN SIC

CAN SIC transceivers provide significant system benefits over regular CAN-FD transceivers without the need for design changes on the physical or application layer. These transceivers enable operation at faster bit rates, with more freedom in choosing a network topology, while reducing vehicle cost and weight.

CAN SIC is backwards-compatible to ISO 11898-2, so it can operate on the same bus as CAN-FD.

As shown in Table 1-1, CAN SIC transceivers significantly improve bit-timing symmetry, which enables more margin for any network effects that can deteriorate CAN signals. The transceiver introduces much less degradation to the transmitted and received bits, reducing the bit duration to operate reliably at 8 Mbps. And finally, the loop delay of CAN SIC transceivers is 190 ns max, compared to 255 ns max for CAN-FD transceivers, helping extend the maximum network length.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2022, Texas Instruments Incorporated