Technical White Paper

How automotive-qualified electromagnetic-compliant 3.3V CAN FD transceivers improve ECU performance

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ABSTRACT

Modern-day automotive systems provide a plethora of functions to help improve vehicle safety, performance and comfort. Design engineers create powertrains for advanced driver assistance systems, body electronics and lighting, infotainment and safety systems that include a large number of electronic control units (ECUs) to perform various electromechanical functions. ECUs exchange control and data-log information through in-vehicle network buses. Among network protocols such as 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 features.

Until now, a majority of CAN transceivers deployed in vehicles have been based on a 5V driver and receiver supply. This is because the CAN physical layer (International Organization for Standardization [ISO] 11898-2:2024) and CAN component-level electromagnetic compliance (EMC) standard (International Electrotechnical Commission [IEC] 62228-3) provide specifications and pass/fail limits only for 5V-supplied CAN transceivers. There are subsystems that need a 5V power rail only for the CAN transceiver. A 3.3V-supplied CAN transceiver can simplify the power-stage designs of ECUs by eliminating the required 5V rail, while being fully interoperable with 5V CAN transceivers on the same network bus and meeting strict automotive EMC requirements. This white paper introduces TI’s TCAN3403-Q1 and TCAN3404-Q1 automotive-qualified and EMC-certified 3.3V CAN Flexible Data Rate (FD) transceivers.

Table of Contents

List of Figures

List of Tables

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1 Introduction

With the electrification of vehicles happening at a rapid pace, multiple ECUs are deployed all through the vehicle. These subsystems talk to each other through a CAN network.

Figure 1-1 shows a CAN network.

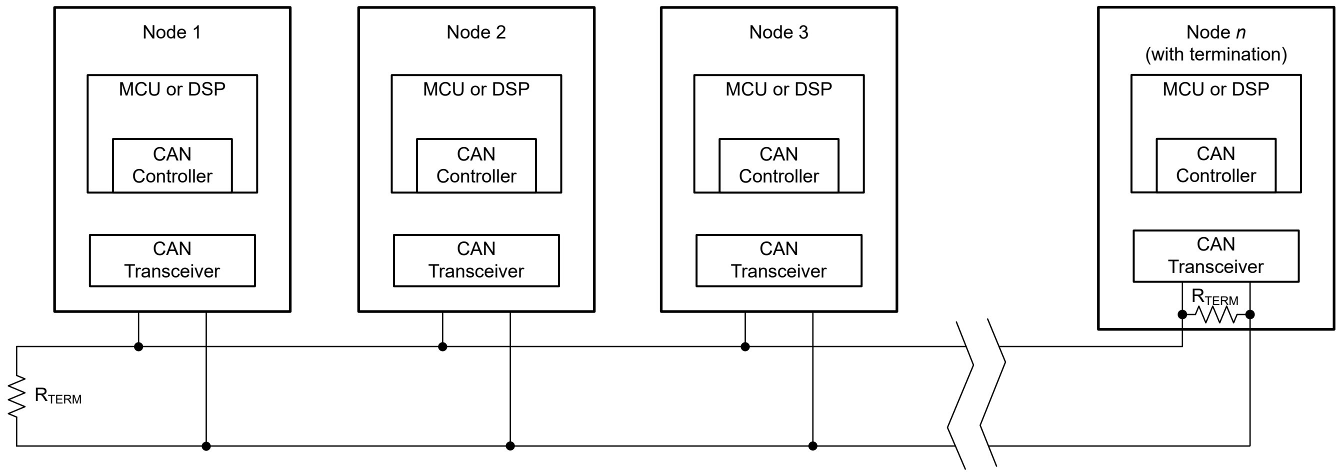

Figure 1-1. Typical CAN Network

Each CAN node consists of at least three components: a CAN transceiver, a microcontroller (MCU) or microprocessor (MPU), with an embedded CAN protocol controller and a power device (a DC/DC converter or linear regulator) that converts the automotive battery voltage to 5V. Additionally, in case the MCU or MPU's input/output (I/O) voltage is 3.3V, a separate 3.3V power device is used on the ECU's printed circuit board (PCB). Figure 1-2 shows a simplified schematic.

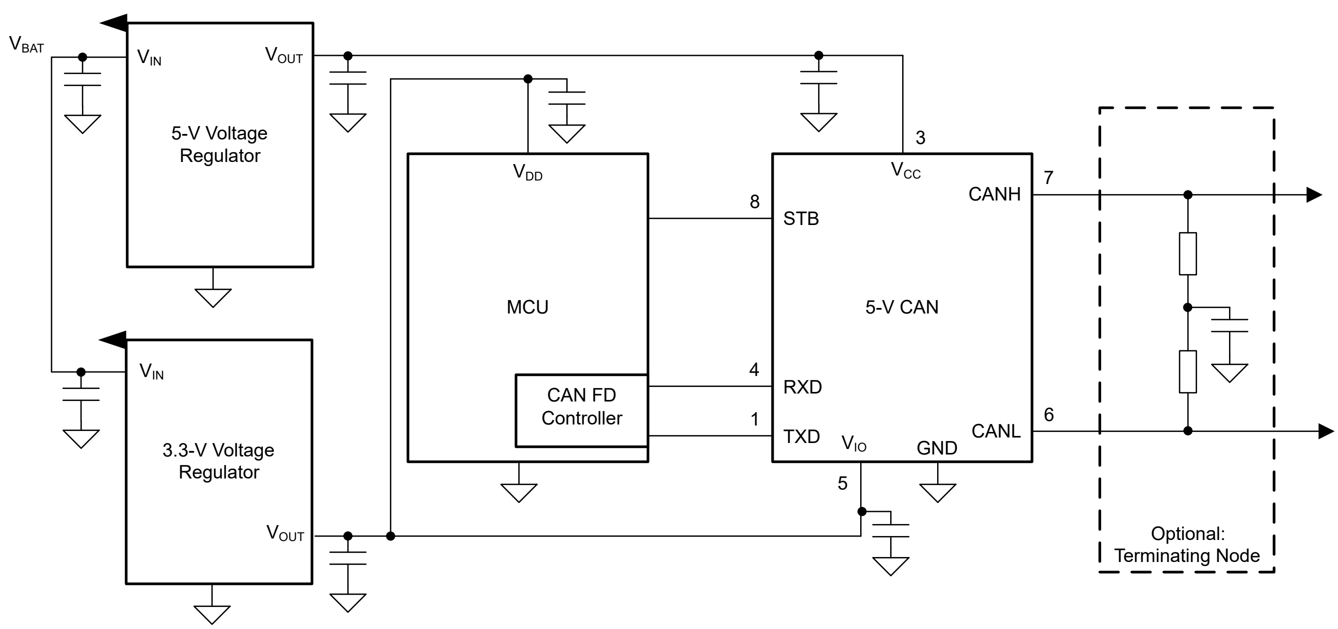

Figure 1-2. Application Schematic of a 5V CAN Transceiver

Typical CAN bus signals consist of dominant and recessive phases. A CAN driver produces a differential signal of at least 1.5V across a 60Ω load during the dominant phase, whereas the driver weakly biases the bus to a common-mode 2.5V level during the recessive phase. This signaling is designed for bitwise arbitration, and the device with the highest priority ID (the CAN frame identification field with the most dominant bits) takes control of the bus, since the dominant (strong) drive is able to overcome recessive (weak) biasing. The receiving nodes monitor CAN high and CAN low differential signals and can decode the CAN message as long as the signal is above 900mV (the dominant threshold) or below 500mV (the recessive threshold).

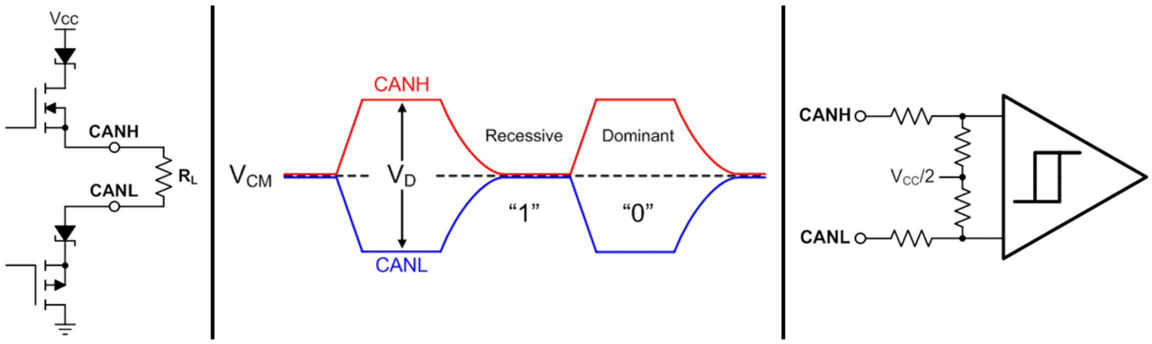

Figure 1-3. CAN Signaling, Diver and Receiver Representation

$V_D = V_{CANH} - V_{CANL}$

For driver: $V_{OD(DOM)} \geq 1.5V$ @ 60 Ω load

For receiver: $V_{ID(DOM)} \geq 900mV$, $V_{ID(rec)} \leq 500mV$

A CAN wiring harness is spread throughout the vehicle. Any common-mode disturbance generated by the CAN transceiver can result in emissions that can impact the functionality of other automotive subsystems. Similarly, the harness is susceptible to electromagnetic interference from other modules. Thus, electromagnetic compliance is an important requirement for any automotive CAN transceiver. Different subsystems can have CAN transceivers from different semiconductor vendors; thus, interoperability is another requirement for any CAN transceiver to be used in a mainstream vehicle network.

2 5V CAN Transceiver

As shown in Figure 2-1, for the driver to produce a minimum differential voltage of 1.5V across the CAN high and CAN low terminals, high- and low-side transistors (highlighted in the dotted-red rectangle in Figure 2-1) must be sized appropriately so that the maximum drop across them is 3V when operating from a 4.5V supply (since the main 5V supply can vary by ±10%).

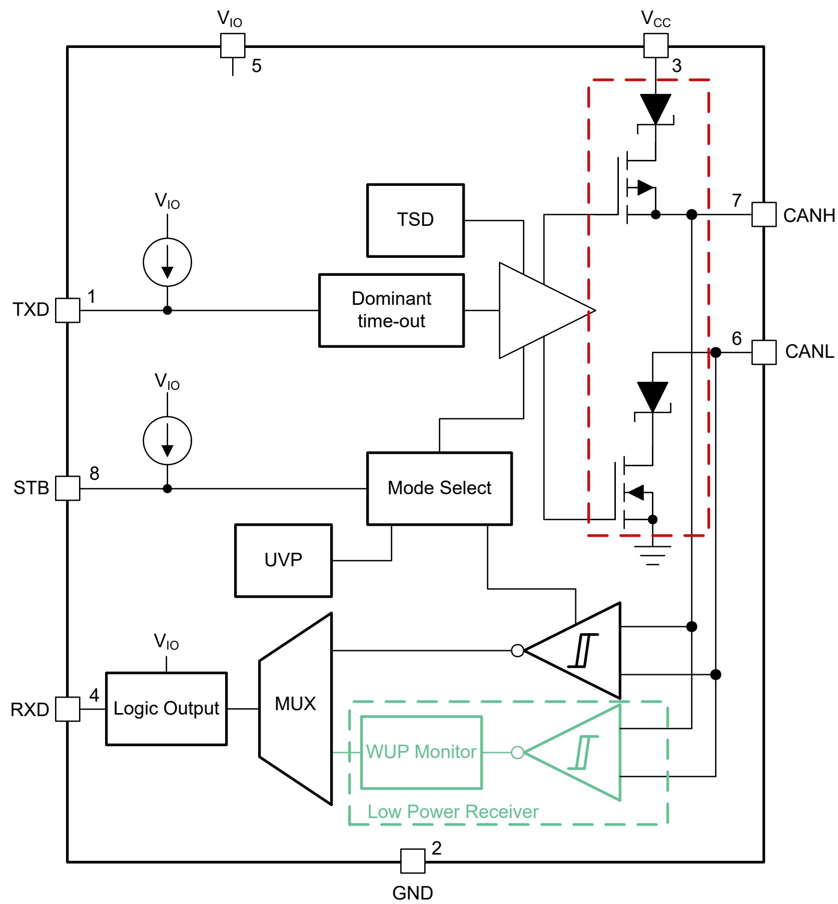

Figure 2-1. CAN Transceiver Block Diagram

The CAN bus transceiver may be the only 5V component in the subsystem. With the modern MCU's I/O supply going down to 3.3V, it is possible to eliminate the 5V rail altogether, resulting in power-stage simplification and cost savings by reducing the bill of materials and PCB space. A high bus-fault-tolerant CAN bus transceiver that is footprint-compatible to standard 5V CAN transceivers, and that operates from a single 3.3V supply, can help simplify designs and reduce cost by eliminating the need for a dedicated 5V supply.

Table 2-1. 5V CAN Transceiver Specifications

Parameter	Conditions	Min (V)	Max (V)
V_{CANH}	Dominant output, Bus load 50 Ω ≤ R_L ≤ 65 Ω	2.75	4.5
V_{CANL}		0.5	2.25

3 TI's TCAN3403-Q1, TCAN3404-Q1 CAN FD Transceivers

TI has released two automotive-qualified and EMC-certified 3.3V CAN FD transceivers. Table 3-1 shows the differences between the TCAN3403-Q1 and TCAN3404-Q1.

Table 3-1. TCAN340x-Q1 Family of Devices

Part Number	Pin 5	Pin 8
TCAN3403-Q1	Ultra-low power shutdown mode	Low power standby mode with remote wakeup
TCAN3404-Q1	Low voltage I/O support	

A few more things to note:

- Even with 3V minimum supply (since 3.3V main supply can vary by ±10%), the devices are designed for a minimum 1.5V of differential output voltage with a 50Ω bus load. This maintains compliance to the VOD specification in ISO 11898-2(2024).
- Receiver thresholds are exactly same as standard 5V CAN transceivers and maintains compliance to ISO11898-2 (2024).
- Single-ended specifications are listed in Table 3-2, which is a slight deviation from CAN physical layer standard ISO 11898-2(2024).

Table 3-2. 3.3V CAN Transceiver Specifications

Parameter	Conditions	Min (V)	Max (V)
V_{CANH}	Dominant output, Bus load 50 Ω ≤ R_L ≤ 65 Ω	2.25	V_{CC}
V_{CANL}		0.5	1.25
V_{CANH}, V_{CANL}	Recessive	1.9 V (typical)	

Driver transistors (highlighted in dotted red rectangle in Figure 2-1) have to be sized so that the drop across the high and low sides is a combined 1.5V maximum at a 3V operating bus supply. This reduction in the minimum operating supply mandates device recessive biasing to be positioned at 1.9V, as opposed to 2.5V for standard 5V CAN transceivers. Because CAN is a differential interface, single-ended voltages in the dominant and recessive states are not crucial for proper operation or communication. This means that the devices are compatible with ISO 11898-2 (2024).

Figure 3-1 is an application diagram with TCAN3404-Q1 demonstrating single 3.3V supply regulator to run the MCU and the CAN transceiver, thereby eliminating the 5V regulator that standard 5V CAN transceivers need.

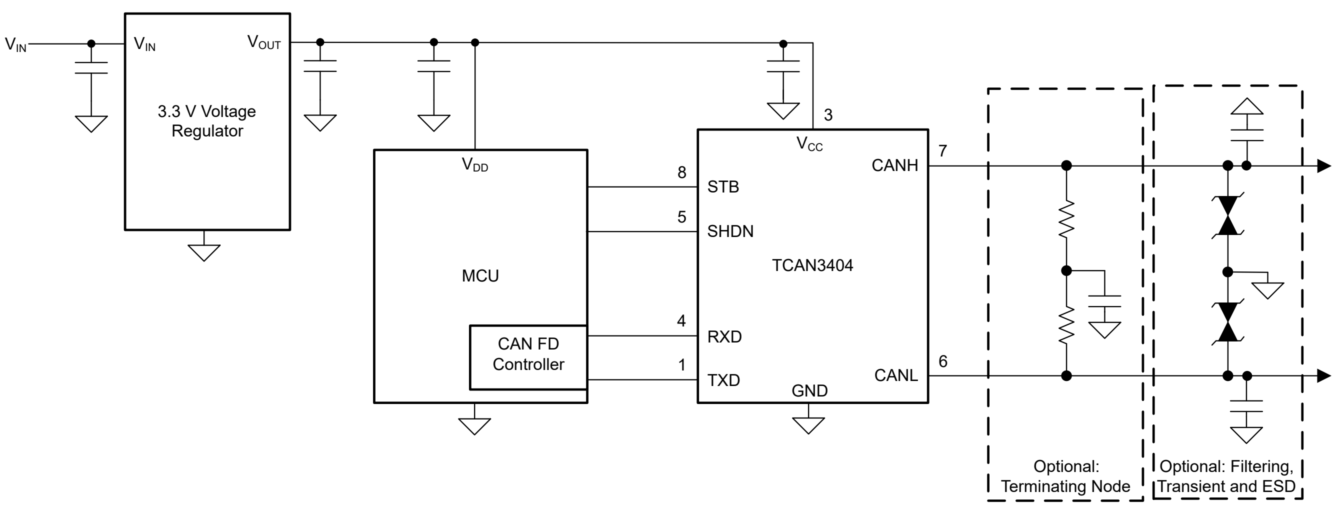

Figure 3-1. Application Schematic of a 3.3V CAN Transceiver

Figure 3-2 compares single device level waveforms between TCAN340x-Q1 and standard 5V CAN.

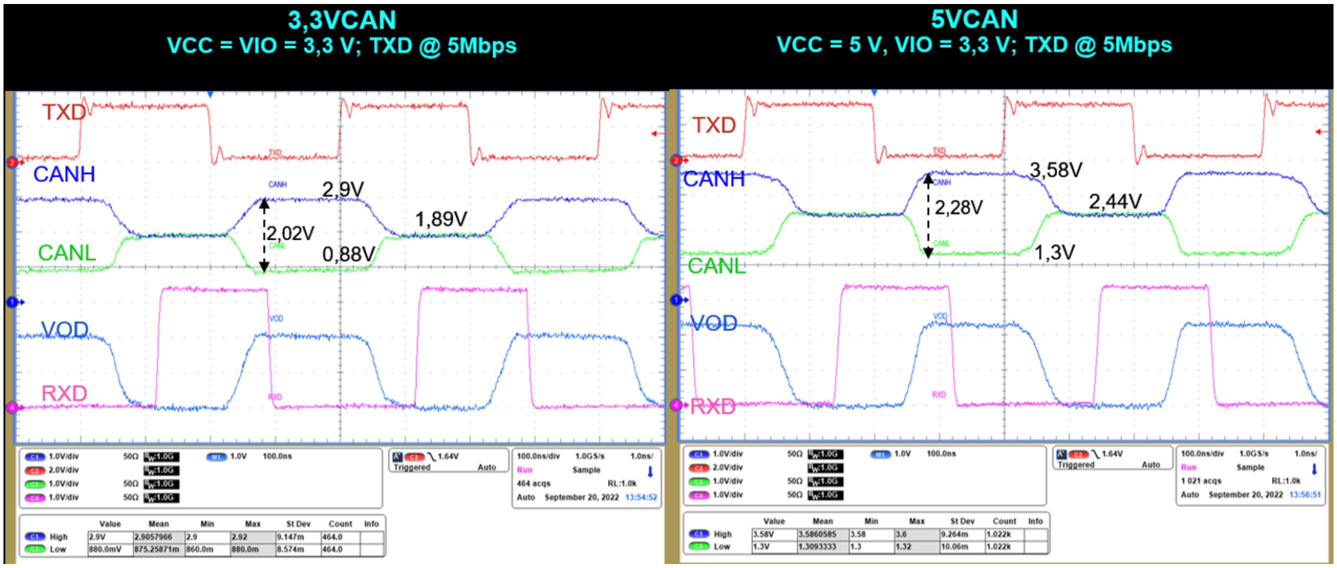

Figure 3-2. Waveform Comparison of a 5V CAN and 3.3V CAN Transceiver

When combining the TCAN3403-Q1 and TCAN3404-Q1 with 5V CAN transceivers on the same bus network, a slight recessive bias mismatch can have an impact on emissions. But proprietary design techniques implemented in both devices maintain EMC compliance per IEC 62228-3 in both homogeneous (both nodes in network, as in the TCAN340x-Q1) and heterogeneous (one node is the TCAN340x-Q1, the other node is standard 5V CAN) network conditions.

Other features of the TCAN3403-Q1 and TCAN3404-Q1 are:

- A high bus-fault tolerance up to ±58V that maintains no device damage in the event of miswiring faults for 12V and 24V battery applications.
- An extended common-mode operating voltage range of ±30V ensures the receiver continues to receive data without disruption, even in the presence of a large ground potential difference or voltage interference.
- Footprint compatibility to standard 5V CAN transceivers, while also having a shutdown feature that reduces supply current consumption to <5μA, enabling seamless upgradability.
- Package options offered in leaded small-outline integrated circuit (SOIC)-8, leadless very small-outline no-lead (VSON)-8 with wettable flanks, and ultrasmall leaded small-outline transistor (SOT)-23.

Many 3.3V CAN transceivers were already available in the market, but none met both auto-qualification and EMC certification requirements. The TCAN340x-Q1 is an option for automotive designers looking for a fully interoperable 3.3V CAN transceiver that overcomes EMC challenges in heterogeneous networks.

4 Interoperability (IOPT) of TCAN340x-Q1

As stated in the previous section, the TCAN340x-Q1 recessive biasing of CAN high and CAN low terminals is 1.9V. This minor shift in common-mode voltage (compared to 2.5V for standard 5V CAN transceivers) falls within the common-mode voltage range of −12V to +12V specified in ISO 11898-2 (2024). Also, this minor shift in recessive bias level is inconsequential to the extended ±30V common-mode voltage range of the TCAN340x-Q1 when operating at 3.3V, allowing the TCAN340x-Q1 to communicate seamlessly with any other ISO 11898-2-compliant transceivers. The TCAN340x-Q1 is fully interoperable with other transceivers on the same bus powered by a 5V supply.

TI's TCAN340x-Q1 3.3V CAN transceiver family has been successfully tested by the internationally recognized third-party communications and systems group to the interoperability test specification for a high-speed CAN transceiver. The TCAN340x-Q1 devices successfully passed homogeneous and heterogeneous network testing, and certificates are available upon request.

In the C&S IOPT tests, TCAN340x-Q1 was tested in a 16-node linear homogenous network with all nodes at 2Mbps, and the device was tested in an 8-node homogeneous linear network at 5Mbps. Additionally, it was with a 16-node 2Mbps network testing under heterogeneous condition (specifically four nodes being TCAN340x-Q1 and 12 nodes being golden reference 5V CAN transceivers). Similarly, an 8-node 5Mbps network was tested in heterogeneous condition (two nodes being TCAN340x-Q1 and 6 nodes as golden reference 5V CAN transceivers). Under all network conditions, failures such as CAN bus short to GND, CAN short to battery, ground shift between nodes and disconnection of nodes were intentionally introduced in the network on startup, then failure was removed and communication integrity was checked. Additionally, TI performed internal testing for various different networks (multi-node complex star topologies) with and without arbitration, and TCAN340x-Q1 passed IOPT under all network conditions. Below are two waveforms during arbitration for homogeneous (all 5V nodes) and heterogeneous (three TCAN340x-Q1 and 8 standard 5V CAN nodes) 11-node complex triple star network tested at 2Mbps data rate (with 500kbps arbitration). Waveforms clearly demonstrated RXD without any errors. Even though bus common mode VCM movement occurred during the frame for heterogeneous condition, differential bus and RXD waveforms remained undisturbed and comparable to all 5V homogeneous network conditions.

Below are two waveforms during arbitration for homogeneous (all 5V nodes) and heterogeneous (three TCAN340x-Q1 and 8 standard 5V CAN nodes) 11-node complex triple star network tested at 2Mbps data rate (with 500kbps arbitration). Waveforms clearly demonstrate RXD is received without any errors. Even though bus common mode V_{CM} movement happens during the frame for heterogeneous condition, differential bus and RXD waveforms remain undisturbed and comparable to all 5V homogeneous network condition.

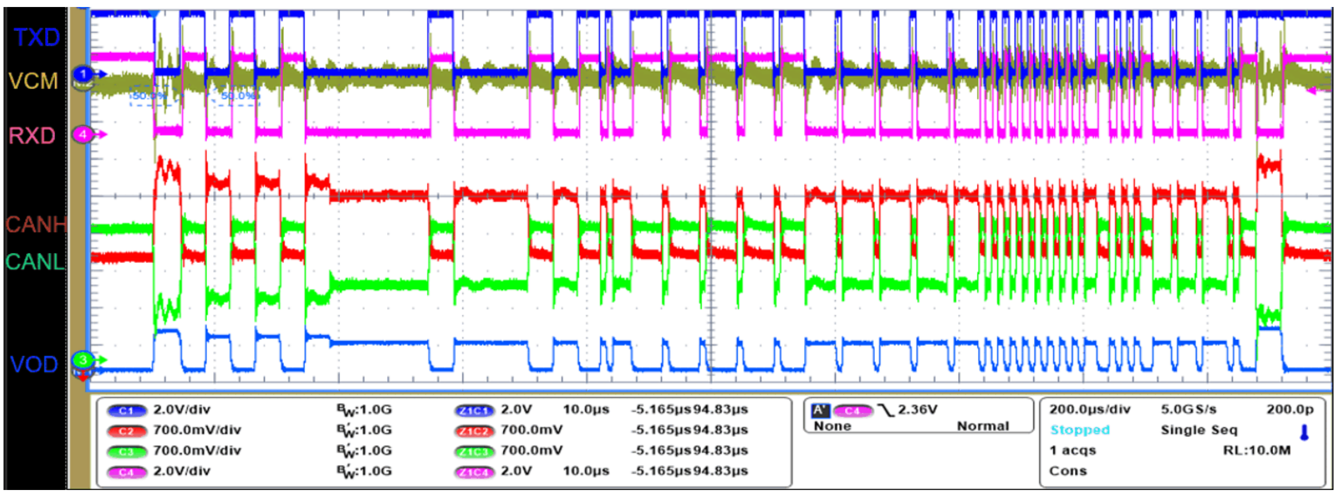

Figure 4-1. 5V Homogeneous Network CAN FD Frame Waveform

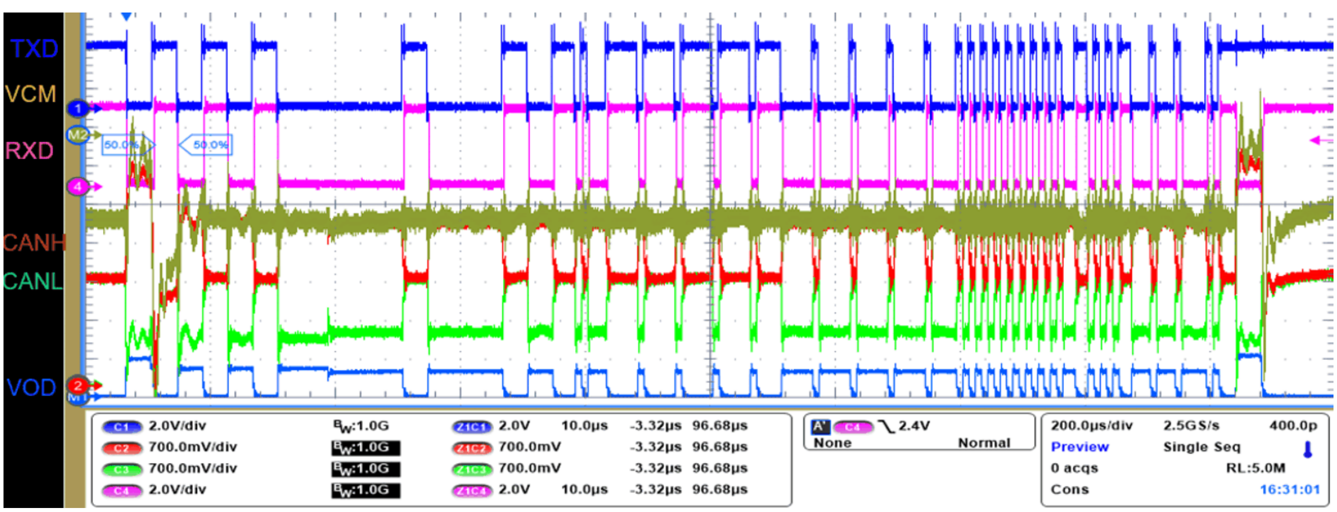

Figure 4-2. 3.3V and 5V Heterogeneous Network CAN FD Frame Waveform

5 EMC of TCAN340x-Q1

As stated in previous sections, meeting component level EMC is a strict requirement to get CAN transceiver qualified at major car makers. One standard that is used to test and qualify CAN transceivers for EMC is IEC62228-3:2019. This standard tests CAN transceivers for conducted emissions and conducted immunity in a two-node setup, and for ISO10605 ESD and pulse transients.

CAN being a differential interface, electromagnetic energy due to differential signals largely gets canceled out, but any common mode mismatch can show up on cable harnesses and result in significant system level emissions. To meet EMC, significant design effort has been made in TCAN340x-Q1 to keep switching symmetry between CANH and CANL during rising and falling bus transitions. Additionally, proprietary design techniques are implemented in TCAN340x-Q1 that dynamically adjusts the bus common mode while driving and receiving CAN data to meet emissions specifically in heterogeneous networks. Emissions in homogeneous network (where all nodes on CAN bus are 3.3V) is easier to meet compared to the stricter heterogeneous network (mix of 3.3V and 5V CAN node on same bus) because of the movement of common mode during recessive condition.

TCAN340x-Q1 meets strict EMC requirements per IEC 62228-3:2019 under both homogeneous and heterogeneous network conditions and passing reports are available upon request.

6 Benefits of TCAN340x-Q1 over competition 3.3V CAN offerings

Table 6-1. Feature Comparison of TCAN340x-Q1 Against Competition 3.3V CAN Devices

Parameter	Competition A	Competition B	Competition C	TCAN340x-Q1	System Implication
Automotive qualified	No	No	No	Yes	Only TI is automotive qualified
EMC certified	No	No	No	Yes	Only TI is automotive EMC certified
CAN bus standoff	±36V	±40V	±60V	±58V	TI is able to work for 12V and 24V automotive battery sub-systems
Receiver common mode voltage range	±25V	±25V	±36V	±30V	TI has extended operating common mode range
Maximum data rate	1Mbps	5Mbps	4Mbps	8Mbps	Operation guaranteed to CAN FD data rates and beyond
Supply current standby mode	600μA	60μA	NA	17μA	Lower standby current consumption reduces battery voltage drain

7 Conclusion

TI's EMC-certified 3.3V CAN transceiver TCAN340x-Q1 offers a compelling alternate to automotive designers against a standard 5V CAN transceiver. It is footprint compatible, and fully interoperable with 5V CAN transceivers while being compatible with physical layer ISO11898-2:2024 specifications. TCAN340x-Q1 helps reduce CAN solution cost by 25% (eliminates automotive 5V LDO) and PCB space by 70%. TCAN340x-Q1 marks the beginning of a new era in 3.3V CAN FD transceivers helping to remove the 5V supply rail traditionally needed in an application only for the 5V CAN transceiver and reducing the BOM cost and PCB size.

8 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (June 2024) to Revision A (July 2024) **Page**

- Updated Section Abstract.......1
- Updated Section 1.......2
- Updated Section 2.......4
- Updated Section 3.......5
- Updated Section 4.......6
- Updated Section 7.......8

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