Application Note
TLE8250VSJ

About this document

Scope and purpose

This document provides application information for the transceiver TLE8250VSJ from Infineon Technologies AG as Physical Medium Attachment within a Controller Area Network (CAN).

This document contains information about:

- set-ups for CAN application
- improved CAN FD parameters
- mode control
- fail safe behavior
- power supply concepts
- power consumption aspects
- PCB recommendations for CAN FD applications
- pin FMEA

This document refers to the data sheet of the Infineon CAN Transceiver TLE8250VSJ.

Note: The following information is given as a hint for the implementation of our devices only and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device.

Intended audience

This document is intended for engineers who develop applications.

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1 CAN Application

With the growing number of electronic modules in cars the amount of communication between modules increases. In order to reduce wires between the modules CAN was developed. CAN is a Class-C, multi master serial bus system. All nodes on the bus system are connected via a two wire bus. A termination of R_T = 120 Ω or a split termination ($R_{T/2}$ = 60 Ω and C_T = 4.7 nF) on two nodes within the bus system is recommended.

An ECU typically consists of:

- power supply
- microcontroller with integrated CAN protocol controller
- CAN transceiver

The CAN protocol uses a lossless bit-wise arbitration method of conflict resolution called CSMA/CA (Carrier Sense Multiple Access/ Collision Avoidance).This requires all CAN nodes to be synchronized. The complexity of the network can range from a point-to-point connection to hundreds of nodes. A simple network concept using CAN is shown in **Figure 1**.

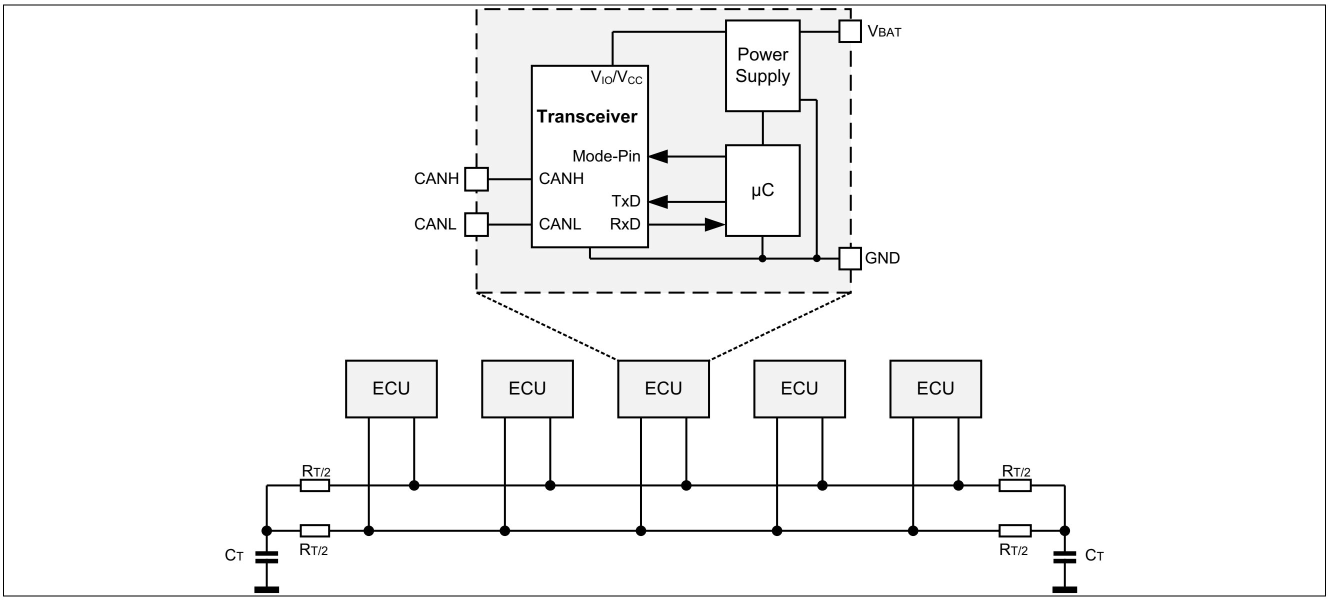

Figure 1 CAN Example with Typical ECU Using TLE8250VSJ

The CAN bus physical layer can have the following states (see **Figure 2**):

- dominant:
  - TxD pin set to "low" generates dominant state
  - voltage at CANH changes towards V_{CC}
  - voltage at CANL changes towards GND
- recessive:
  CANH and CANL are biased to $V_{CC}/2$

See **Table 1** for voltage levels specified for dominant and recessive state.

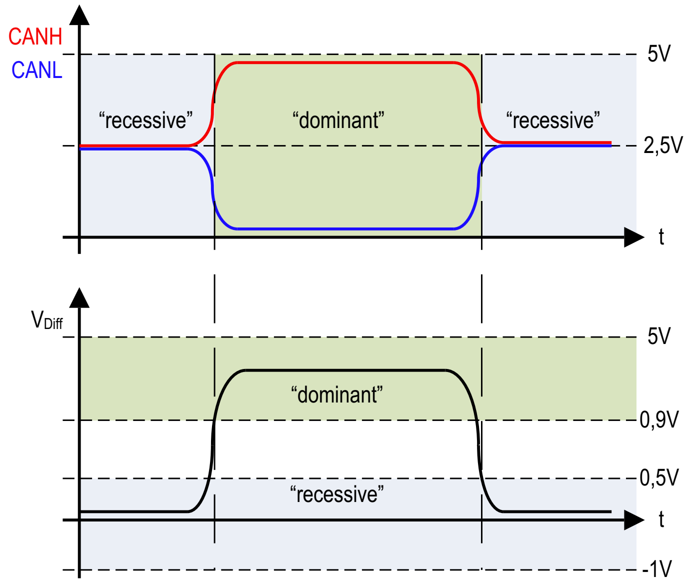

Figure 2 Voltage Levels according to ISO 11898-2

Table 1 Voltage Levels according to ISO 11898-2

Parameter	Symbol	Values			Unit	Note or Test Condition
		Min.	Typ.	Max.		
Recessive State						
Output Bus Voltage	$V_{CANL,H}$	2.0	2.5	3.0	V	No load
Differential Output Bus Voltage	$V_{Diff\_R\_NM}$	-500	–	50	mV	No load
Differential Input Bus Voltage	$V_{Diff\_R\_Range}$	-3.0	–	0.5	V	–
Dominant State						
Output Bus Voltage	V_{CANH}	2.75	3.5	4.5	V	$50\ \Omega < R_L < 65\ \Omega$
	V_{CANL}	0.5	1.5	2.25	V	$50\ \Omega < R_L < 65\ \Omega$
Differential Output Bus Voltage	$V_{Diff\_D\_NM}$	1.5	2.0	3.0	V	$50\ \Omega < R_L < 65\ \Omega$
Differential Input Voltage	$V_{Diff\_D\_Range}$	0.9	–	8.0	V	–

ISO 11898-2 describes the CAN physical layer. The CAN transceiver TLE8250VSJ fulfills all parameters defined in ISO 11898-2. This document describes CAN applications with the TLE8250VSJ. It provides application hints and recommendations for the design of CAN electronic control units (ECUs) using the CAN transceiver TLE8250VSJ from Infineon.

2 TLE8250VSJ Description

The transceiver TLE8250VSJ represents the physical medium attachment, that is the interface between the CAN protocol controller and the CAN transmission medium. The CAN transceiver converted the transmit data stream of the protocol controller at the TxD input to a bus signal. The receiver of the TLE8250VSJ detects the data stream on the CAN bus and transmits it to the protocol controller via the RxD pin.

2.1 Features

The main features of the TLE8250VSJ are:

- Baud rate up to 2 Mbit/s with improved CAN FD parameters (see **Chapter 4.2**)
- Very low Electromagnetic Emission (EME) and high Electromagnetic Immunity (EMI)
- Excellent ESD performance according to HBM (+/-10 kV) and IEC (+/-8 kV)
- Very low current consumption in Power-save mode: 14 µA
- Transmit data (TxD) dominant time-out function
- Supply voltage range 4.5 V to 5.5 V
- Control input levels compatible with 3.3 V and 5 V devices

2.2 Mode Description

The TLE8250VSJ supports three different modes of operation. The mode of operation depends on the status of the reference power supply and the status of the mode selection pin NEN, :

Table 2 Description of Modes

Mode	Use Cases
Normal-operating mode	• Used for communication on the HS CAN bus • Transmit and receive data on the bus
Power-save mode	• Reduced current consumption in afterrun when there is no communication on the HS CAN bus with ECU still active. • Emergency undervoltage state, when the microcontroller detects undervoltage and starts saving internal information. • For current consumption reduction the transceiver is set to Power-save mode.
Forced-power-save mode	• Same behavior as Power-save mode • Fail-safe mode for V_{CC} undervoltage condition • Reduced current consumption in afterrun when there is no communication on the HS CAN bus with ECU still active. • Emergency undervoltage state when the microcontroller detects undervoltage and starts saving internal information.

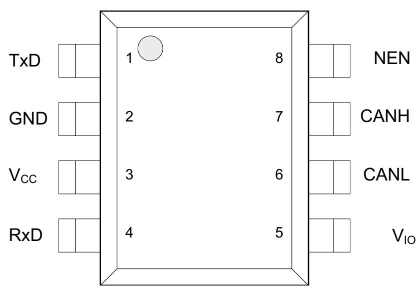

Figure 3 Pin Configuration of the TLE8250VSJ

2.3 TLE825x-Family Pin-out Compatibility

The TLE825x-Family is pin-out and functional compatible to existing Infineon CAN transceivers (see **Figure 4**). The TLE825x-Family consists of:

- TLE8250SJ
- TLE8250VSJ
- TLE8250XSJ
- TLE8251VSJ

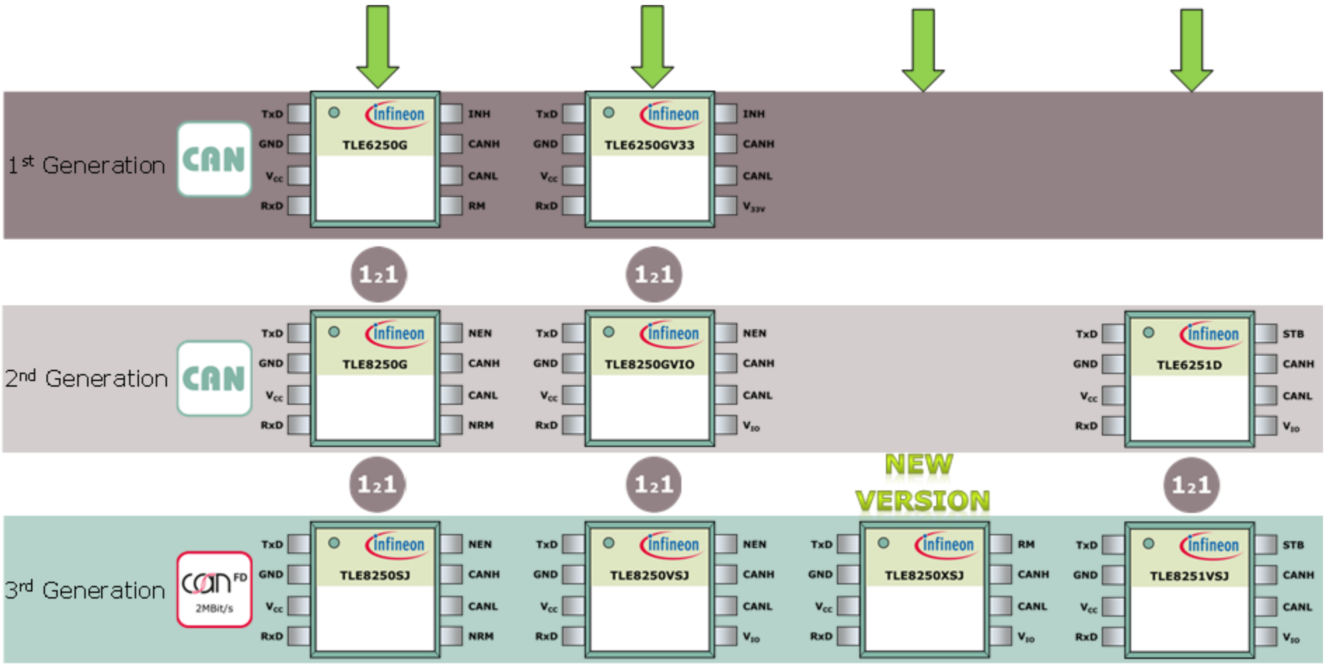

Figure 4 TLE825x-Family Pin-out Compatibility

3 In-Vehicle Network Applications

The TLE8250/51-Family offers a perfect match for various ECU requirements. TLE8250VSJ offers improved loop delay symmetry to support CAN FD data frames up to 2 MBit/s (see **Chapter 4.2**). For partially supplied ECUs (Clamp 15) the TLE8250VSJ is suitable. According to the requirements of automobile manufacturers, the modules can either be permanently supplied or unsupplied when the car is parked. The main purpose for unsupplied modules is saving battery energy. A CAN message can wake up permanently supplied modules.

3.1 Clamp 30 and Clamp 15

Clamp 30 (permanently supplied networks, connected to battery)

Body applications such as door modules, RF keyless entry receivers require permanently supplied modules. Permanently supplied modules are still powered when the car is not in use. The supply line from the battery is called clamp 30. Because battery voltage is present permanently, the voltage regulator, transceiver and microcontroller are always supplied. Voltage regulators, transceivers and microcontrollers need to be set to low-power mode. Low power mode reduces current consumption and prevents the battery from draining.

Clamp 15 (partially supplied networks, connected to ignition)

Under hood applications such as ECUs typically use partially supplied modules. When the car is parked a main switch or ignition key switches off the battery supply. This supply line is called clamp 15. When the battery voltage is not present, the voltage regulator and transceiver are switched off.

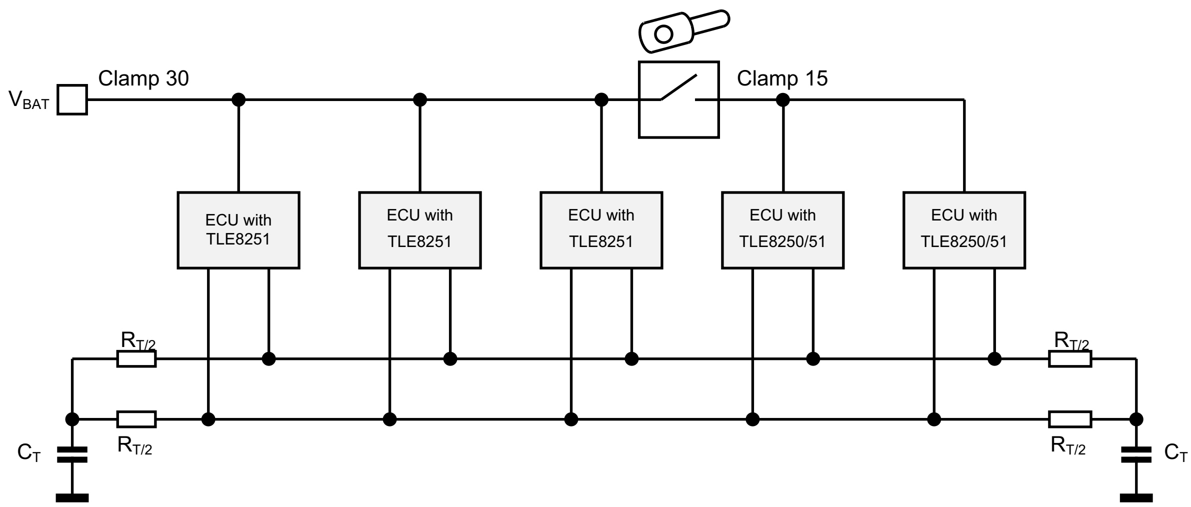

Figure 5 CAN with ECUs Using TLE8250VSJ

In Clamp 15 applications there is no for transceivers with bus wake-up feature. Therefore TLE8250VSJ offers three different modes that make applications more flexible (see **Chapter 2.2**). For applications that do not use the bus wake-up feature, the TLE8250VSJ offers a Power-save mode with very low current consumption. If the TLE8250VSJ is disconnected from the power supply, current consumption of the ECU decreases further. The perfect passive bus behavior of the TLE8250VSJ does not affect CAN bus communication while the TLE8250VSJ is not supplied.

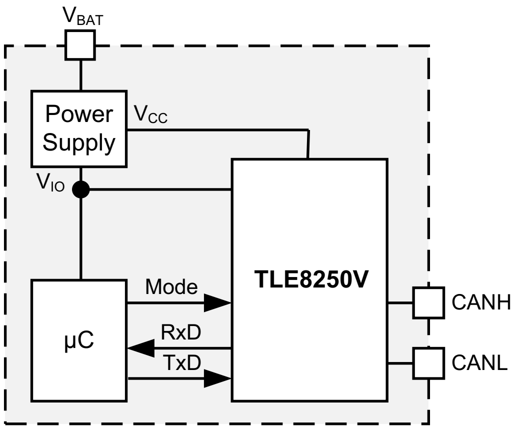

Figure 6 Example ECU with TLE8250VSJ

3.2 Baud Rate versus Bus Length

Table 3 Recommended Baud Rate versus Bus Length

Baud Rate (kbit/s)	Bus Length (m) Maximum Distance between two Nodes
1000	10
500	40
250	120
125	500
50	1000

Baud rate is limited by:

- bus length
- ringing
- propagation delay of cables
- propagation delay of the CAN controller of the transceiver

The two most distant nodes (A and B) in a CAN network are the limiting factor in transmission speed. The propagation delays must be considered because a round trip has to be made from the two most distant CAN controllers on the bus. Propagation delay of the cable depends on cable length and on temperature.

In the worst case scenario node A starts transmitting a dominant signal and it takes a certain period of time ($t = t_{CANcontroller} + t_{Transceiver} + t_{Cable}$) until the signal reaches node B.

Propagation delay is the sum of:

- CAN controller delay
- transceiver delay
- bus length delay

Assumption: 70 ns for CAN controller, 255 ns for transceiver, 5 ns per meter of cable. Example with 50 m cable length:

$t_{prop} = t_{CANcontroller} + t_{Transceiver} + t_{Cable} + t_{CANcontroller} + t_{Transceiver} + t_{Cable} =$
70 ns + 255 ns + 50 m × 5 ns/m + 70 ns + 255 ns + 50 m × 5 ns/m = 1150 ns

With a total propagation delay of 1150 ns and assuming a nominal bit time of 2000 ns, the timing window for the sampling point is reduced to 850 ns not taking into account ringing or reflections. For correct bit sampling this timing window should include additional timing margin.

Other factors of strong influence on the maximum baud rate are:

- cable capacitance
- oscillator tolerance
- ringing
- reflections, depending on the network topology

The shorter the bus length, the timing window margin increases and a higher data rate can be achieved. Wire resistance increases with bus length and therefore the bus signal amplitude may be degraded. For additional information please refer to **The Physical Layer in the CAN FD World**.

4 CAN FD

CAN FD (Flexible Data Rate) is the advanced version of classical CAN.

CAN FD saves transmission time compared to classical CAN:

- increased data transmission rate
- increased payload per message

CAN FD includes additional timing parameters.

Table 4 Classical CAN vs. CAN FD

	Data transmission rate [Mbit/s]	Maximum payload message length [byte]
Classical CAN	1	8
CAN FD	2	64

4.1 General Information

CAN FD uses the same physical layer as classical CAN does. During the arbitration phase and checksum the data transmission rate is identical to classical CAN (1 Mbit/s). As soon as one node in the CAN FD network starts transmitting the payload, the data rate is increased (2 Mbit/s). The increased baud rate is possible, because only one node transmits during the data transmission phase. All other nodes listen to the data on the CAN bus. In order to ensure reliable data transmission, CAN FD requires a CAN transceiver with full ISO 11898-2 specification for Flexible Data rate up to 2 Mbit/s.

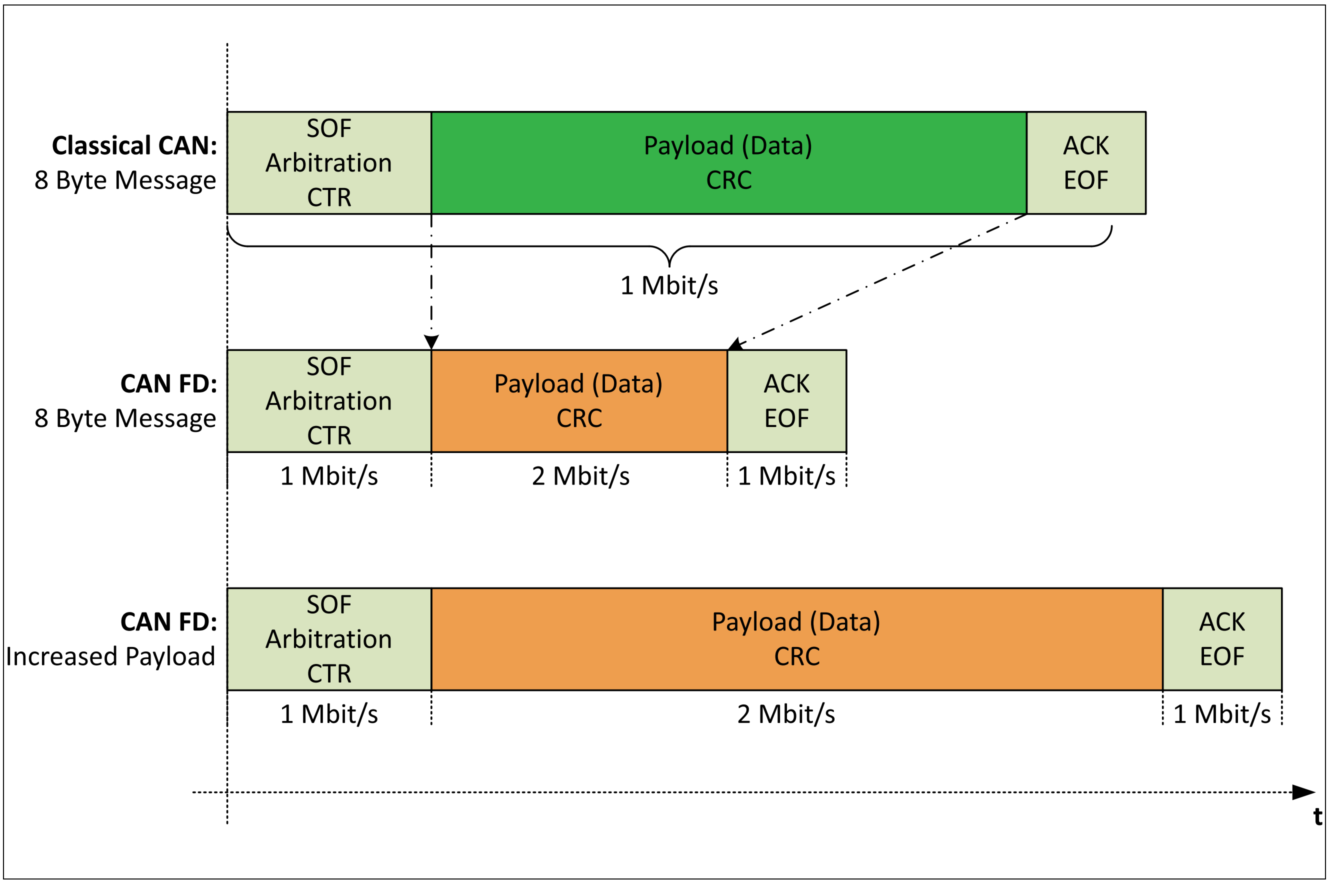

Figure 7 Classical CAN Data Rate and CAN FD Data Rate

4.2 TLE8250VSJ Improved CAN FD Parameters

The TLE8250VSJ from Infineon is the perfect match for CAN FD networks. TLE8250VSJ exceeds the CAN FD parameters according to ISO 11898-2 (Edition 2016) for 2 Mbit/s in order to enable smooth and safe usage within applications. The TLE8250VSJ offers improved loop delay symmetry to support CAN FD data frames up to 2 MBit/s (see **Table 5**).

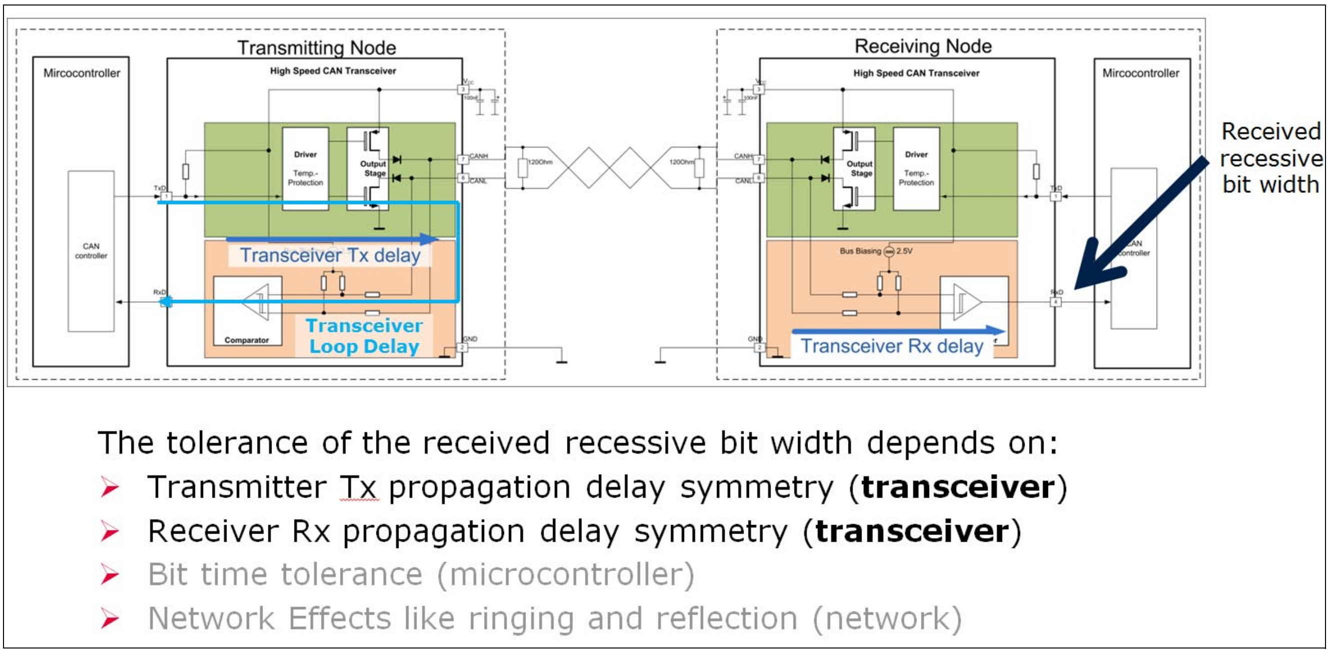

Figure 8 Transceiver Propagation Delay

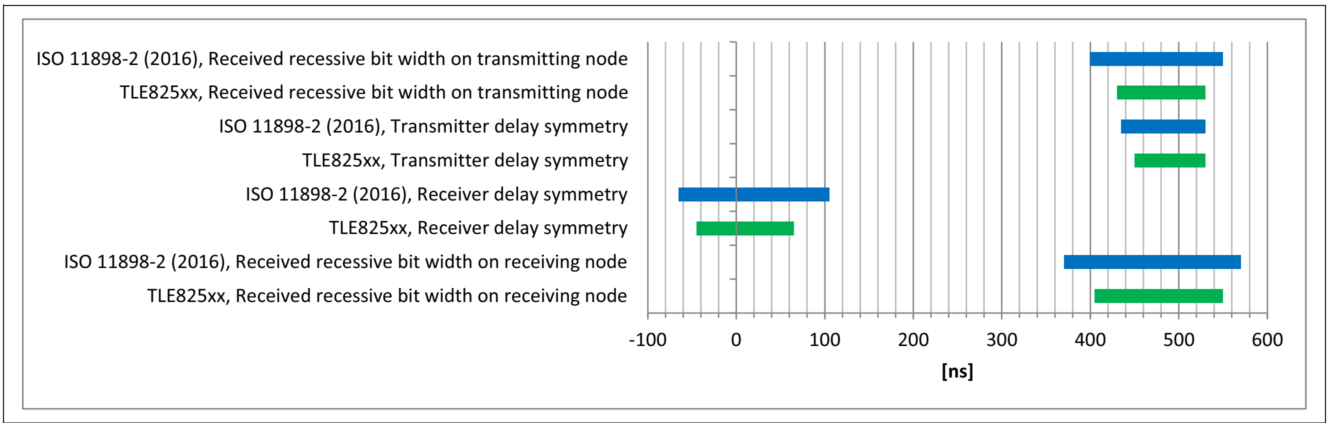

Figure 9 Improved CAN FD parameters: ISO 11898-2 (2016) vs. TLE82xx

Table 5 Improved CAN FD parameters: ISO 11898-2 (2016) vs. TLE8250VSJ

Specification	**ISO 11898-2 (2016) Specification**			**TLE8250VSJ Specification**		
Parameter	min.	max.	Unit	min.	max.	Unit
Received recessive bit width on transmitting node	400	550	ns	430	530	ns
Transmitter delay symmetry	435	530	ns	450	530	ns
Receiver delay symmetry	-65	+40	ns	-45	+20	ns
Received recessive bit width on receiving node $t_{Bit(RxDrec)}$	370	570	ns	405	550	ns

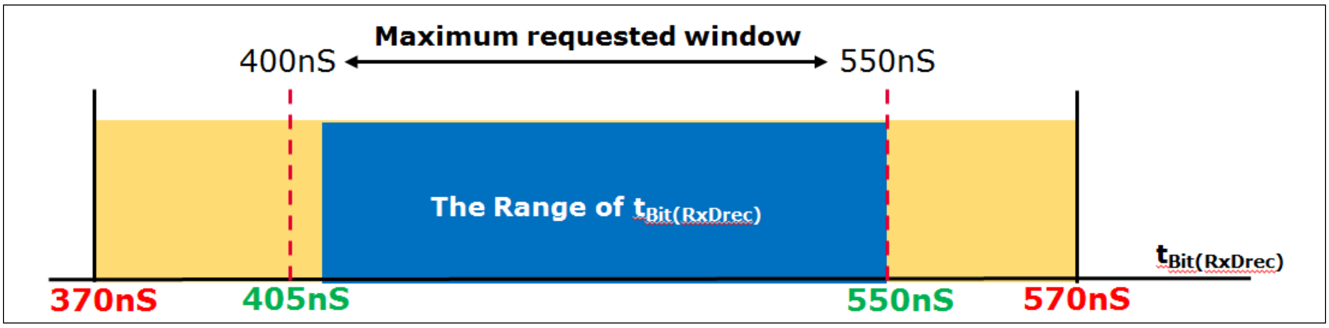

Figure 10 Requested maximum $t_{Bit(RxDrec)}$ by Japanese OEM for CAN FD

Figure 10 shows the maximum requested range of the received recessive bit width on the receiving node $t_{Bit(RxDrec)}$ by Japanese OEMs. Infineon's TLE8250VSJ Transceiver fulfills the requested maximum window of $t_{Bit(RxDrec)}$. TLE8250VSJ has improved timing parameters for CAN Flexible Data Rate (2Mbit/s), which adds additional safety margin for network effects like ringing effects and network propagation delay.

4.3 TLE8250VSJ Approval in Conjunction with Common Mode Choke

For applications using Classical CAN and CAN Flexible Data Rate, Japanese OEMs require always a Common Mode Choke. Infineon TLE8250VSJ CAN Transceiver is qualified and approved at Japanese OEMs with all major Common Mode Chokes:

- ACT45B type
- ACT45C type
- DLW43 type

5 Pin Description

5.1 V_{IO} Pin

The V_{IO} pin is needed for the operation with a microcontroller that is supplied by $V_{IO} < V_{CC}$, to match the voltage level between microcontroller and transceiver. It can also be used to decouple microcontroller and transmitter supply.

Benefits of using the V_{IO} pin:

- improved EMC performance
- the transmitter supply V_{CC} can be switched off separately

The digital reference supply voltage V_{IO} has two functions:

- supply of the internal logic of the transceiver (state machine)
- voltage adaption for external microcontroller (3.0 V < V_{IO} < 5.5 V)

As long as V_{IO} is supplied (V_{IO} > 3.0 V) the state machine of the transceiver supports mode changes. If a microcontroller uses low $V_{IO} < V_{CC}$ = 5 V, then the V_{IO} pin must be connected to the power supply of the microcontroller. Due to the V_{IO} pin feature, the TLE8250VSJ can work with various microcontroller supplies. If V_{IO} is available, then both transceiver and microcontroller are fully functional. Below V_{IO} < 3.0 V the TLE8250VSJ is in Power On Reset state. To enter Normal-operating mode V_{IO} ≥ 3.0 V is required.

5.2 V_{CC} Pin

The V_{CC} pin supplies the transmitter output stage.

Table 6 Transmitter state depending on V_{CC}

V_{CC}	Transmitter state	Note
$V_{CC} < V_{CC\_UV}$	disabled	3.65 V < V_{CC_UV} < 4.3 V
$V_{CC\_UV} < V_{CC}$ < 4.5 V	enabled; parameters may be outside the specified range	–
4.5 V < V_{CC} < 5.5 V	enabled	–
V_{CC} > 6 V	damage of TLE8250VSJ possible	–

5.3 GND Pin

The GND pin must be connected as close as possible to module ground in order to reduce ground shift. It is not recommended to place filter elements or an additional resistor between GND pin and module ground. GND must be the same for transceiver, microcontroller and HS CAN bus system.

5.4 RxD Pin

RxD is an output pin. The data stream received from the HS CAN bus is displayed on the RxD output pin in Normal-operating mode. Do not use a series resistor within the RxD line between transceiver and microcontroller. A series resistor may add delay, which degrades the performance of the transceiver, especially in high data rate applications.

5.5 TxD Pin

TxD is an input pin. TxD pin receives the data stream from the microcontroller. If in Normal-operating mode $V_{IO} > V_{IO\_UV}$, then the data stream is transmitted to the HS CAN bus. In all other modes the TxD input pin is

blocked.A “low” signal causes a dominant state on the bus and a “high” signal causes a recessive state on the bus. The “high” signal must be adapted to the voltage on the V_{IO} pin. This means the “high” level must not exceed V_{IO} voltage. The TxD input pin has an integrated pull-up resistor to V_{IO}. If TxD is permanently “low”, for example due to a short circuit to GND, then the TxD time-out feature will block the signal on the TxD input pin (see **Chapter 8.1**). Do not use a series resistor within the TxD line between transceiver and microcontroller. A series resistor may add delay, which degrades the performance of the transceiver, especially in high data rate applications.

5.6 NEN Pin

The NEN pin sets the mode of TLE8250VSJ and is usually directly connected to an output port of a microcontroller. For a disconnected NEN pin or microcontroller ports in tristate the TLE8250VSJ has an integrated pull-up resistor to V_{IO}, by default the device is in Power-save mode in order to enable low current consumption. This reduces disturbance to the HS CAN bus. **Table 7** shows mode changes via the NEN pin, assuming $V_{IO} > V_{IO\_UV}$. **Chapter 2** describes features and modes of operation.

Table 7 Mode Selection via NEN

Mode of operation	NEN	V_{CC}	Note	Receiver	Transmitter
Power-Save Mode	“high”	“X”[1]	–	disabled	disabled
Forced-Power-Save Mode	“low”	$< V_{CC\_UV}$	Same as Power-save mode	disabled	disabled
Normal-Operating Mode	“low”	$> V_{CC\_UV}$	–	enabled	enabled

1) “X”: don’t care

The Power-save mode and Forced-power-save mode are the low-power modes of TLE8250VSJ. In these modes both the transmitter and the receiver are disabled and current consumption is reduced. The user can deactivate transmitter and receiver of TLE8250VSJ either by setting the NEN pin to “low” or by switching off V_{CC}. This can be used to implement two different fail safe paths in case a failure is detected in the ECU.

5.7 CANH and CANL Pins

CANH and CANL are the CAN bus input and output pins. The TLE8250VSJ is connected to the bus via pin CANH and CANL. Both transmitter output stage and the receiver are connected to CANH and CANL.

Data on the TxD pin is:

- transmitted to CANH and CANL
- simultaneously received by the receiver input and signalled on the RxD output pin.

For achieving optimum EME (Electromagnetic Emission) performance, transitions from dominant to recessive and from recessive to dominant are performed as smooth as possible also at high data rate. Output levels of CANH and CANL in recessive and dominant state are described in **Table 1**. Due to the excellent ESD performance on CANH and CANL no external ESD components are necessary to fulfill OEM requirements.

6 Transceiver Supply

The internal logic of TLE8250VSJ is supplied by the V_{IO} pin. The V_{CC} pin is used to create the CANH and CANL signal. The transmitter output stage as well as the main CAN bus receiver are supplied by the V_{CC} pin. This chapter describes aspects of power consumption and voltage supply concepts of TLE8250VSJ.

6.1 Voltage Regulator

It is recommended to use one of the following Infineon low drop output (LDO) voltage regulators:

- 3.3 V V_{IO} power supply: TLS850D0TAV33 (500mA), TLS850F0TAV33 (500mA), TLS810B1LDV33 (100mA), **TLE4266-2GS V33** (150mA),
- 5 V V_{IO} and V_{CC} power supply: TLS850D0TAV50 (500mA), **TLS850F0TA V50** (500mA), **TLS810D1EJV50** (100mA), **TLS810B1LDV50** (100mA), **TLE4266-2** (150mA)
- 3.3 V and 5 V dual voltage power supply: **TLE4476D**
- Dual 5V voltage power supply: **TLE4473GV55**

Please refer to **Infineon Linear Voltage Regulators** for the Infineon voltage regulator portfolio and data sheets.

6.2 External Circuitry

In order to reduce EME and to improve the stability of input voltage level on V_{CC} and V_{IO} of the transceiver, it is recommended to place capacitors (low impedance and low ESR) close to V_{IO} and V_{CC} on the PCB. During sending a dominant bit to the HS CAN bus, current consumption of TLE8250VSJ is higher than during sending a recessive bit. Data transmission can change the load profile on V_{CC}. Changes in load profile may reduce the stability of V_{CC}. If several CAN transceivers are connected in parallel, and if these CAN transceivers are supplied by the same V_{CC} and/or V_{IO} power supply (for example LDO), then the impact on the stability of V_{CC} is even stronger. It is recommended to place a 100 nF capacitor as close as possible to V_{CC} and V_{IO} pin. The output of the V_{CC} and V_{IO} power supply (for example LDO) must be stabilized by a capacitor in the range of 1 to 50 µF, depending on the load profile. Ceramic capacitors are recommended for low ESR.

6.3 Power-up Sequence for V_{IO} and V_{CC}

As TLE8250VSJ has V_{CC} and V_{IO} supply pin, this chapter describes possible scenarios for powering up the device. V_{CC} supplies the transmitter output stage and V_{IO} the internal state machine of TLE8250VSJ. There is no limitation for the start-up sequence for TLE8250VSJ:

- Scenario 1: If V_{IO} is supplied first, the internal state machine will start to work for $V_{IO} > V_{IO\_UV}$. Then the mode of operation can be changed by the mode selection pins . The transmitter of TLE8250VSJ remains disabled in Normal-operating Mode if $V_{CC} > V_{CC\_UV}$ and also in all other modes.
- Scenario 2: If V_{CC} is supplied first, only the transmitter output stage is supplied. But as V_{IO} is not yet supplied the transmitter is High-Z (disabled) by default, in order to not disturb the bus communication.
- Scenario 3: If V_{CC} and V_{IO} are connected to the same supply voltage (5V), the state machine will start to work for $V_{IO} > V_{IO\_UV}$ (max. 3.0V) and the transmitter will be enabled if $V_{CC} > V_{CC\_UV}$ (max. 4.5V).

6.4 V_{IO} Feature

TLE8250VSJ offers a V_{IO} supply pin, which is a voltage reference input for adjusting the voltage levels on the digital input and output pins to the voltage supply of the microcontroller. In order to use the V_{IO} feature, connect the power supply of the microcontroller to the V_{IO} input pin. Depending on the voltage supply of the microcontroller, TLE8250VSJ can operate with the V_{IO} reference voltage input within the voltage range from 3.0 V to 5.5 V.

6.4.1 V_{IO} 3.0 V - 5.5 V Power Supply Concept

The V_{IO} pin supplies the internal logic of the TLE8250VSJ. TLE8250VSJ can operate with the V_{IO} reference voltage input in the range from 3.0 V to 5.5 V. The V_{CC} pin (typ. = 5 V) supplies the transmitter of TLE8250VSJ. Therefore the V_{CC} supply input pin must be connected to a 5 V voltage regulator. Competitor devices use V_{CC} to supply the internal logic and the transmitter output stage and V_{IO} as a simple level shifter. Infineon's HS CAN transceivers can work in V_{CC} undervoltage condition or even with V_{CC} completely switched off in Forced-power-save mode and Power-save mode.

6.4.2 V_{IO} 3.3 V Power Supply

In order to reduce power consumption of ECU, the microcontroller might not be supplied by V_{CC} but by a lower voltage (for example 3.3 V). Therefore the TLE8250VSJ offers a V_{IO} supply pin, which is a voltage reference input in order to adjust the voltage levels on the digital input and output pins to the voltage supply of the microcontroller. The V_{IO} feature enables the TLE8250VSJ to operate with a microcontroller, which is supplied by a voltage lower than V_{CC}. With the V_{IO} reference voltage input the TLE8250VSJ can operate from 3.0 V to 5.5 V.

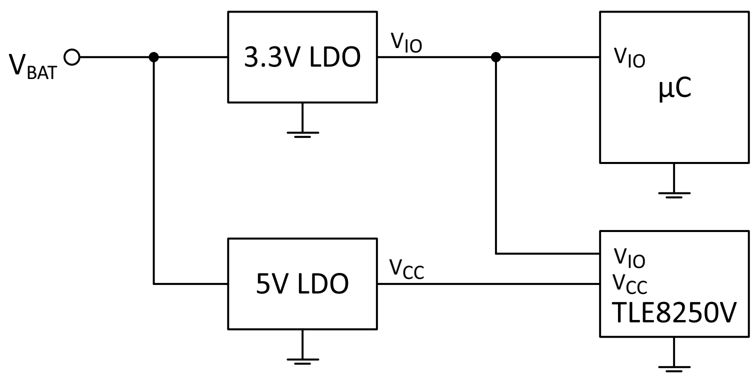

Figure 11 3.3 V Power Supply Concept

6.4.3 V_{IO} 5 V Supply

TLE8250VSJ can also operate with a 5 V supply because of the V_{IO} input voltage range from 3.0 V to 5.5 V. If the microcontroller uses V_{CC} = 5 V supply, then V_{IO} is connected to V_{CC}. The V_{IO} input must be connected to the supply voltage of the microcontroller.

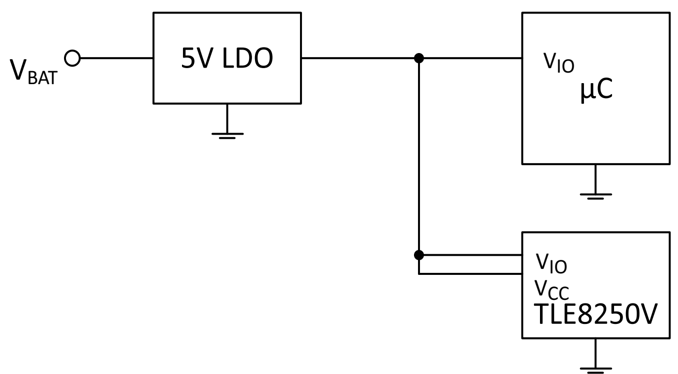

Figure 12 5 V Power Supply Concept

6.4.4 Dual 5 V Supply Concept

In order to decouple the microcontroller and the HS CAN Bus from each other with respect to noise and disturbances, it is possible to use a dual 5 V voltage regulator like **TLE4473GV55**. In this case two independent 5 V LDOs supply V_{IO} and V_{CC}. This power supply concept improves EMC behavior and reduces noise.

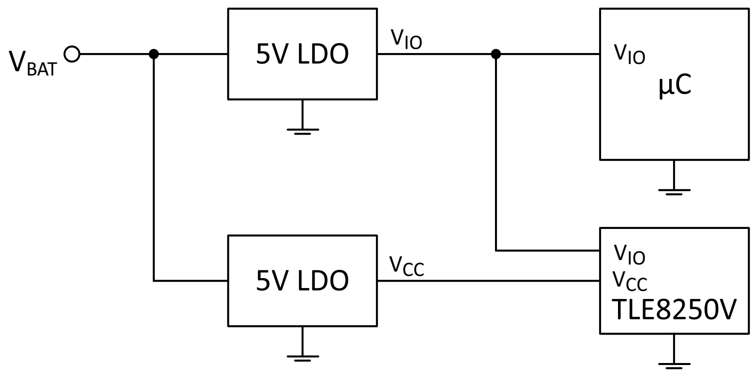

Figure 13 Dual 5 V Power Supply Concept

6.5 Current Consumption

Current consumption depends on the mode of operation:

- Normal-operating mode:
  Maximum current consumption of TLE8250VSJ on the V_{CC} supply is specified as 60 mA in dominant state and 4 mA in recessive state. Maximum current consumption of TLE8250VSJ on the V_{IO} supply is specified as 1 mA. To estimate theoretical current consumption in Normal-operating mode, a duty cycle of 50% can be assumed, with fully loaded bus communication of 50% dominant and 50% recessive. In Normal-operating mode the TLE8250VSJ consumes in worst case maximum:
  $I_{CC\_AVG} = (I_{CC\_REC} + I_{CC\_DOM}) / 2 + I_{IO} = 32.5$ mA
  Typically the current consumption is less than 15 mA.
- Power-save mode and Forced-power-save mode:
  In Power-save mode most of the functions are turned off. V_{CC} can be switched off. The maximum current consumption is specified as 8 µA.

6.6 Loss of Battery (Unsupplied Transceiver)

When TLE8250VSJ is unsupplied, CANH and CANL act as high impedance. The leakage current $I_{CANH,lk}$, $I_{CANL,lk}$ at CANH pin or CANL pin is limited to +/- 5 µA in worst case. When unsupplied, TLE8250VSJ behaves like a 1 MΩ resistor towards the bus. Therefore the device perfectly fits applications that use both Clamp 15 and Clamp 30.

6.7 Loss of Ground

If loss of ground occurs, then the transceiver is unsupplied and behaves like in unpowered state. Due to the internal input resistors on CANH and CANL on the unpowered transceiver, the HS CAN Bus Signal gets shifted.

In applications with inductive load connected to the same GND, for example a motor, the transceiver can be damaged due to loss of ground. Excessive current can flow through the CAN transceiver when the inductor demagnetizes after loss of ground. The ESD structure of the transceiver cannot withstand that kind of Electrical Overstress (EOS). In order to protect the transceiver and other components of the module, an inductive load must be equipped with a free wheeling diode.

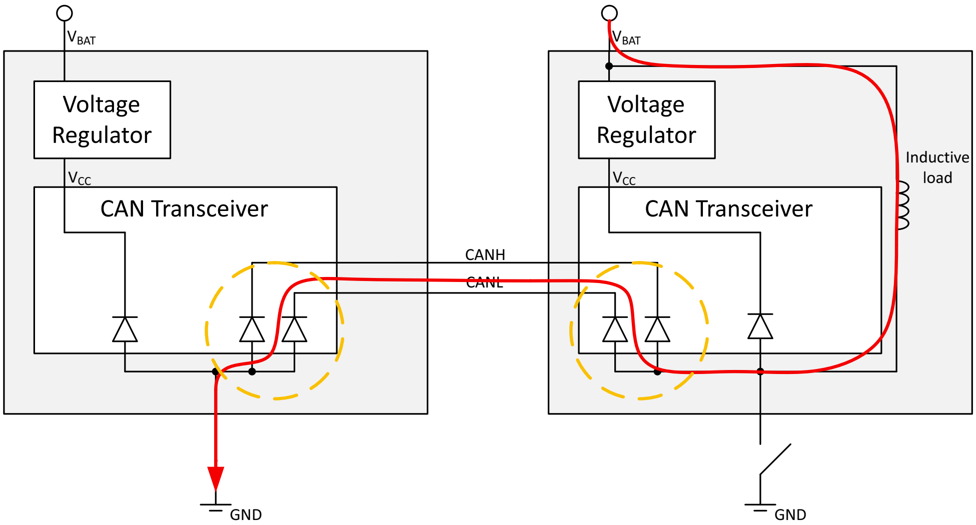

Figure 14 Loss of GND with Inductive Load

6.8 Ground Shift

Due to ground shift the GND levels of CAN transceivers within a network may vary. Ground shift occurs in high current applications or in modules with long GND wires. The receiver input stage acts like a resistor (R_i) to GND. Because the transmitting node has its GND shifted to V_{Shift}, the recessive voltage level V_{rec} from the chassis ground is no longer 2.5 V but $V_{rec} + V_{shift}$. The same ground shift voltage V_{Shift} must be taken into account for the dominant signal. Because CAN uses a differential signal and because of the wide common mode range of +/-12 V for Infineon transceivers, any CANH and CANL DC value within absolute maximum ratings works.

The recessive CAN bus level V_{rec} during a ground shifted node transmitting is equal to the average recessive voltage level of all transceivers:

$V_{rec} = [(V_{rec\_1} + V_{Shift\_1}) + (V_{rec\_2} + V_{Shift\_2}) + (V_{rec\_3} + V_{Shift\_3}) + ... + (V_{rec\_n} + V_{Shift\_n})]/n$

n: number of connected CAN nodes

V_{rec_1}, V_{rec_2}, .., V_{rec_n}: specific recessive voltage level of the transceiver at nodes 1, 2, .. n

V_{Shift_1}, V_{Shift_2}, ..., V_{Shift_n}: specific ground shift voltage level of the transceiver at nodes 1, 2, .. n

The supply current of a ground shifted transceiver increases by $I_{CC\_Shift} = V_{Shift} / (R_{i\_n} / n)$, assuming all input resistances at CANH and CANL of the transceivers are identical.

The higher the ground shift of one node to the other, the higher the Electromagnetic Emission.

7 Transceiver Control

The modes of the TLE8250VSJ are controlled by the pin NEN and by transmitter voltage V_{CC}.

7.1 Mode Change by NEN

The mode of operation is set by the mode selection pin NEN. By default the NEN input pin is "high" due to the internal pull-up resistor to V_{IO}.
The TLE8250VSJ is in Power-save mode independent of the status of V_{CC}. In order to change the mode to Normal-operating mode, NEN must be switched to "low" and V_{CC} must be available.

7.2 Mode Change Delay

The HS CAN transceiver TLE8250VSJ changes the mode of operation within the transition time period t_{Mode}. The transition time period t_{Mode} must be considered in developing software for the application. After the mode change from Power-save mode to a non-low power mode the receiver and/or transmitter is enabled. During the period t_{Mode} the RxD output pin is permanently set to "high" and does not reflect the status on the CANH and CANL input pins. In addition, during t_{Mode}, the TxD path is blocked as well. When the mode change is completed, the TLE8250VSJ releases the RxD output pin. **Figure 15** shows this scenario.

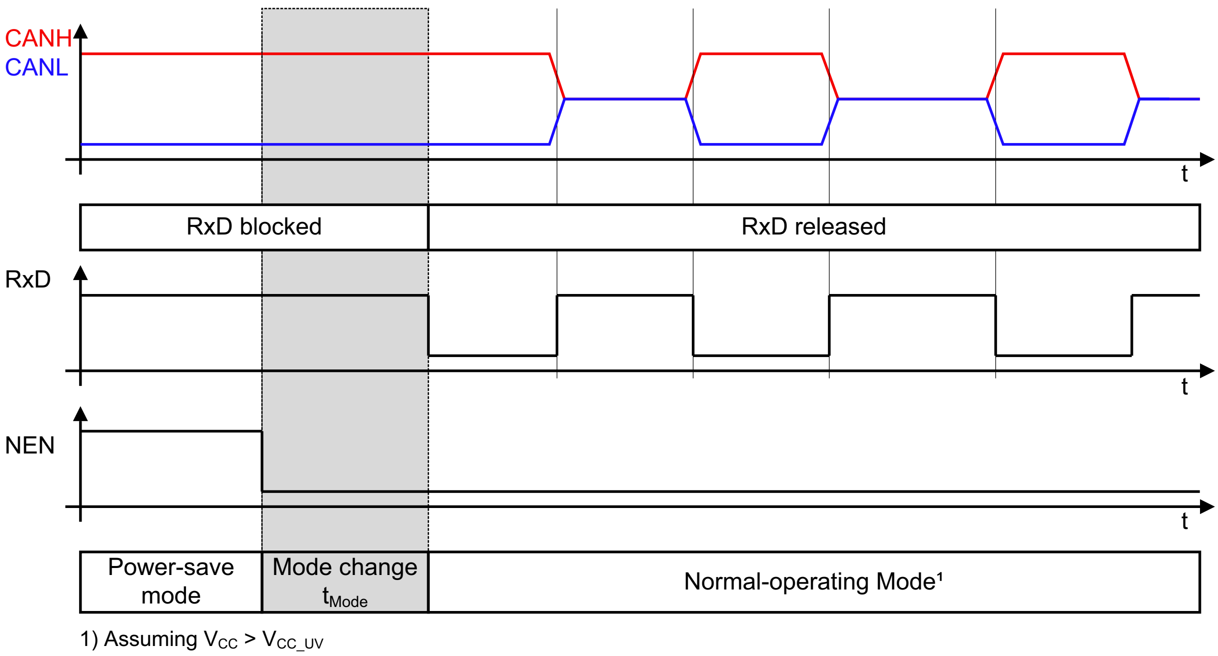

Figure 15 RxD Behavior during Mode Change

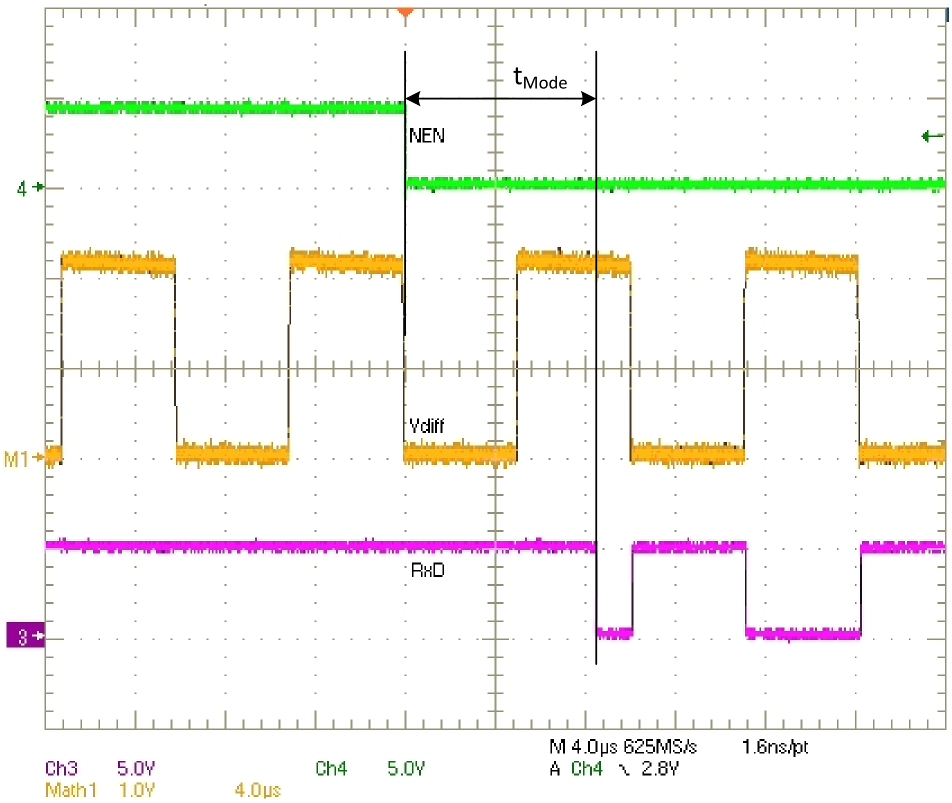

Figure 16 Communication on the CAN Bus: RxD Behavior during Mode Change (Power-Save Mode to Normal-Operating Mode)

7.3 Mode Change due to V_{CC} Undervoltage

A mode change due to V_{CC} undervoltage is only possible in Normal-operating mode. If V_{CC} undervoltage persists longer than $t_{Delay(UV)}$, then the TLE8250VSJ changes from Normal-operating mode to Forced-power-save mode. As soon as TLE8250VSJ detects an undervoltage, it disables the transmitter output stage so that no faulty data is sent to the HS CAN bus.
In order to reduce current consumption during $V_{CC} < V_{CC(UV)}$ fault condition, the TLE8250VSJ has a optimized current consumption in Forced-power-save mode.
If V_{CC} recovers, then $V_{CC} > V_{CC\_UV}$ TLE8250VSJ

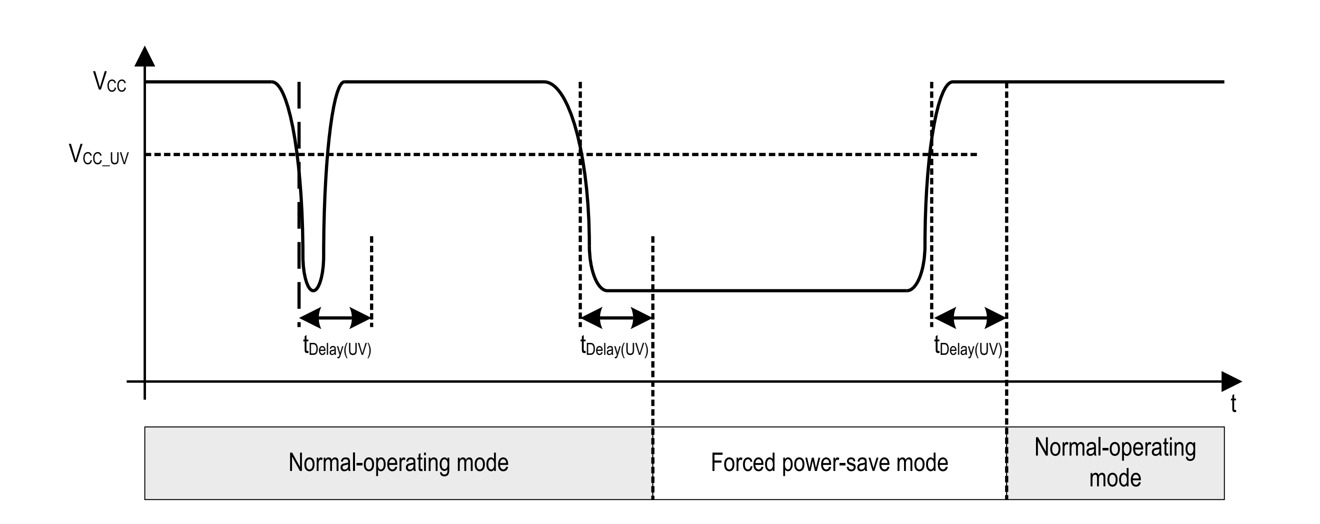

Figure 17 V_{CC} **Undervoltage and Recovery**

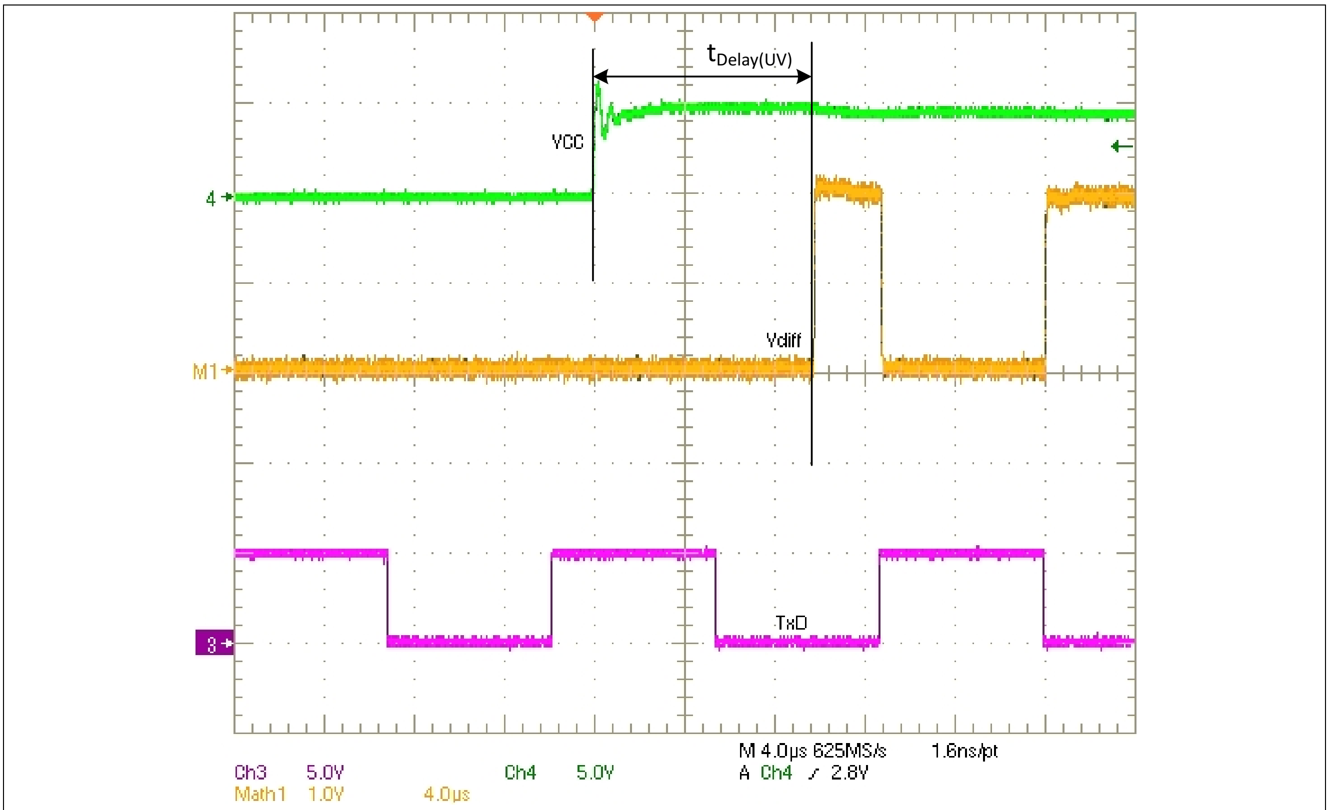

Figure 18 **Recovery of** V_{CC} **in Forced Power-Save Mode**

7.4 Transition from Power-Save Mode to Forced-Power-Save Mode

From Normal-operating mode the TLE8250VSJ enters Forced-power-save mode on detecting V_{CC} undervoltage. However, in Power-save mode V_{CC} undervoltage detection is disabled. With V_{CC} below the undervoltage threshold V_{CC_UV}TLE8250VSJ in Power-save mode, when EN is switched from "high" to "low" the TLE8250VSJ changes to Normal-operating mode. In Normal-operating-mode V_{CC} undervoltage detection is enabled, and thus the undervoltage event is detected. This in turn triggers a mode change to Forced-power-save mode. The overall transition time period from Power-save mode to Forced-power-save Mode is $t < t_{Mode}$. During the mode change from Power-save mode to Forced-power-save mode the RxD output pin is permanently set to "high" and does not reflect the status of the CANH and CANL input pins. After the mode change to Forced-power-save mode is completed, the TLE8250VSJ releases the RxD output pin.

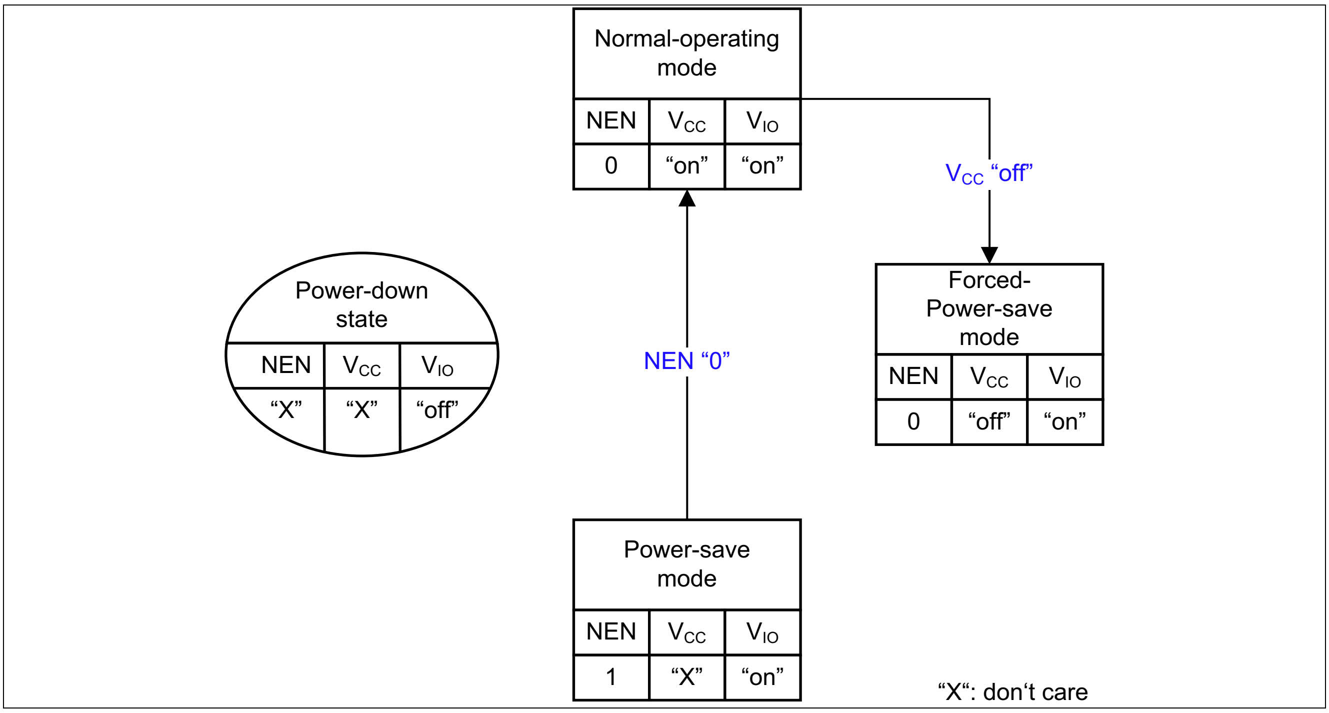

Figure 19 Power-Save Mode to Forced-Power-Save Mode

8 Failure Management

This chapter describes typical bus communication failures.

8.1 TxD Dominant Time-out Detection

The TxD dominant time-out detection of TLE8250VSJ protects the CAN bus from being permanently driven to dominant level. When detecting a TxD dominant time-out, the TLE8250VSJ disables the transmitter in order to release the CAN bus. Without the TxD dominant time-out detection, a CAN bus would be clamped to the dominant level and therefore would block any data transmission on the CAN bus. This failure may occur for example due to TxD pin shorted to ground.

The TxD dominant time-out detection can be reset after a dominant to recessive transition at the TxD pin. A "high" signal must be applied to the TxD input for at least $t_{TXD\_release}$ = 200 ns to reset the TxD dominant timer.

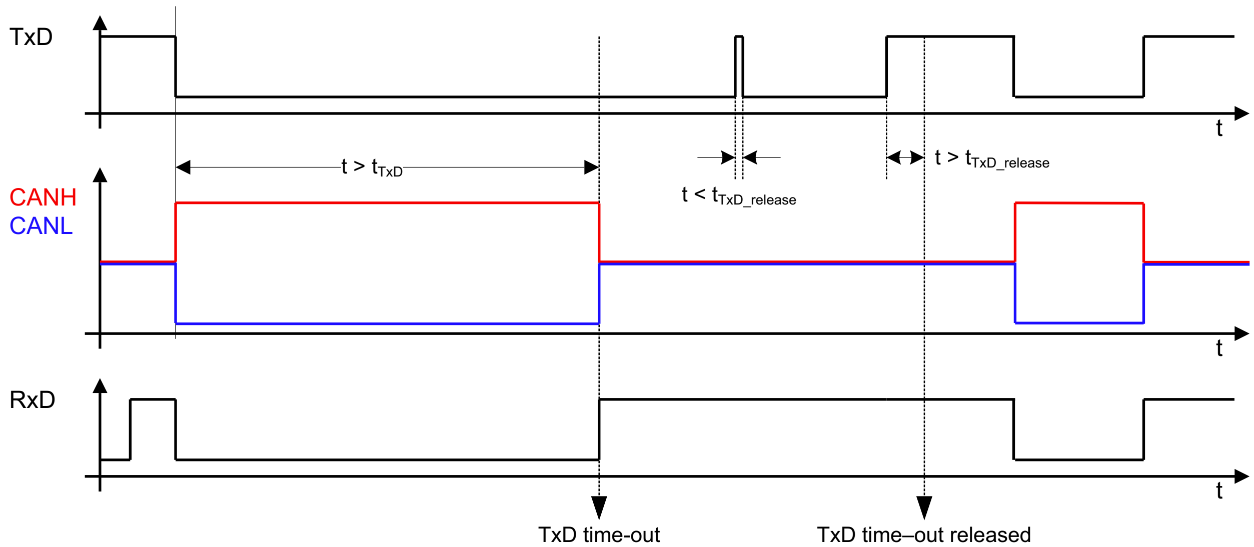

Figure 20 Resetting TxD Dominant Time-out Detection

If a TxD Dominant Time-out is present, then a mode change to Power-save mode clears the TxD dominant timer state.

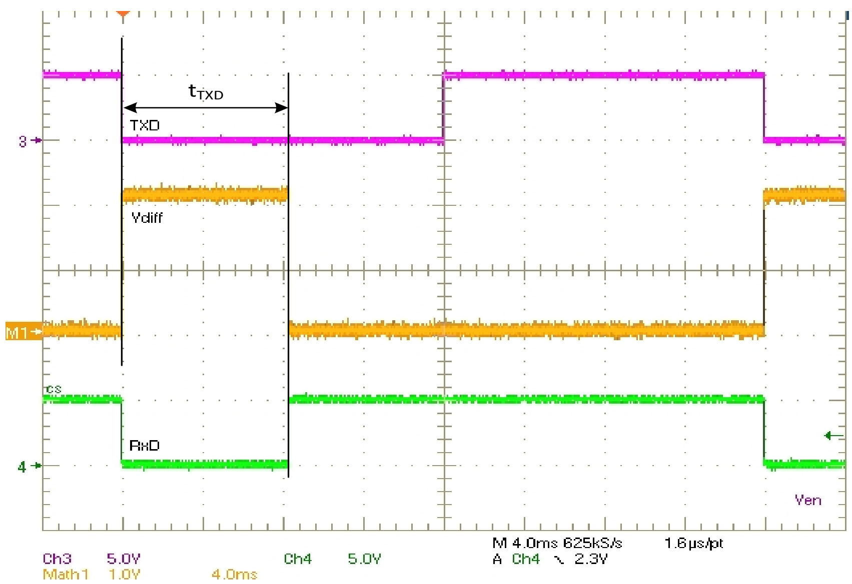

Figure 21 Measurement: TxD Dominant Time-out Detection

8.2 Minimum Baud Rate and Maximum TxD Dominant Phase

Due to the TxD dominant time-out detection of the TLE8250VSJ the maximum TxD dominant phase is limited by the minimum TxD dominant time-out time t_{TxD} = 4.5ms. The CAN protocol allows a maximum of 11 subsequent dominant bits at TxD pin (worst case dominant bits followed immediately by an error frame). With a minimum value of 4.5 ms given in the datasheet and maximum possible 11 dominant bits, the minimum baud rate of the application must be higher than 2.44 kbit/s.

8.3 Short Circuit

Figure 22 shows short circuit types on the HS CAN bus. The CANH and CANL pins are short circuit proof to GND and to supply voltage. A current limiting circuit protects the transceiver from damage. If the device heats up due to a permanent short at CANH or CANL, then the overtemperature protection switches off the transmitter.

Depending on the type of short circuit on CANH and CANL, communication might be still possible. If only CANL is shorted to GND or only CANH is shorted to V_{BAT}, then dominant and recessive states may be recognized by the receiver. Timings and/or differential output voltages might be not valid according to ISO11898 but still in the range for the receiver working properly.

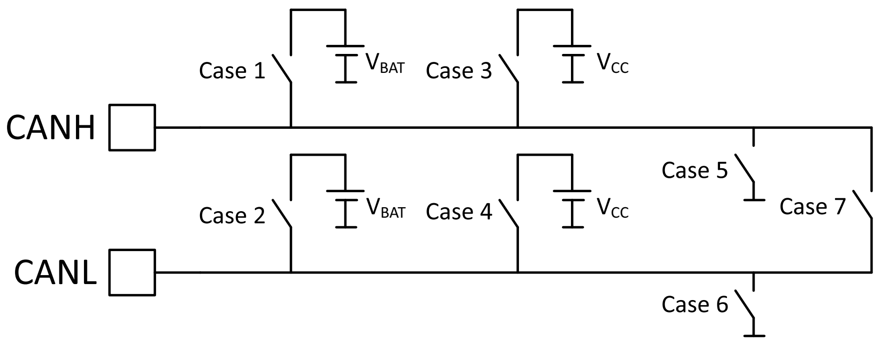

Figure 22 HS CAN Bus Short Circuit Types

Communication on the HS CAN bus is blocked in the following cases:

- CANH and CANL shorted (Case7)
- CANH shorted to GND (Case 5)
- CANL shorted to V_{BAT} (Case 2) or V_{CC} (Case 4)

If a short circuit occurs, then the V_{CC} supply current for the transceiver can increase significantly. It is recommended to dimension the voltage regulator for the worst case, especially when V_{CC} also supplies the microcontroller. V_{CC} supply current increases in dominant state. The recessive current remains unchanged.

CANH shorted to GND

The datasheet specifies a maximum short circuit current of 100mA. When transmitting a dominant state to the bus, 5V is shorted to GND through the transmitter output stage. Power dissipation with 10% duty cycle (DCD) is:

P = DCD x U x I = 0.1 x 5V x 100mA = 0.05W.

The average fault current with worst case parameters and assuming a realistic duty cycle of 10% is:

$I_{CC,Fault} = I_{CC,rec} \times 0.9 + I_{CANH,SC} \times 0.1 =$ 13.6mA.

CANL shorted to V_{BAT}

If CANL is shorted to V_{BAT}, then the current through the CANL output stage is even higher and the device heats up faster. The datasheet specifies a maximum short circuit current of 100mA. When transmitting a dominant state to the bus, V_{BAT} is shorted to GND through the transmitter output stage. Assuming a realistic duty cycle

of 10% for this case and the power dissipation is:
P = DCD x U x I = 0.1 x V_{BAT} x 100mA = 0.1 x 18V x 100mA = 0.18W.

CANH shorted to V_{BAT}

Short circuit of CANH to V_{BAT} can result in a permanent dominant state on the HS CAN bus, due to the voltage drop at the termination resistors of the network. Therefore the termination resistor has to be chosen accordingly. If a short circuit of CANH to V_{BAT} occurs, then the power loss in the termination resistor must be taken into account. **Figure 23** shows the current in case CANH is shorted to V_{BAT}. When transmitting a dominant state to the bus, the current flows through the termination resistor an CANL to GND. Power loss in the termination resistor and CANL assuming a battery voltage of 18 V and a duty cycle of 10% is:

$P_{Loss\_Termination}$ = 0.1 x ($R_{Termination}$ x $I_{CANL,SC}$)x $I_{CANL,SC}$= (60Ω x 100mA) x 100mA = 0.6W

P_{Loss_CANL} = 0.1 x (V_{BAT} - ($R_{Termination}$ x $I_{CANL,SC}$)) x $I_{CANL,SC}$)= 0.1 x (18V-6V) x 100mA = 0.1 x 12V x 100mA = 0.12W

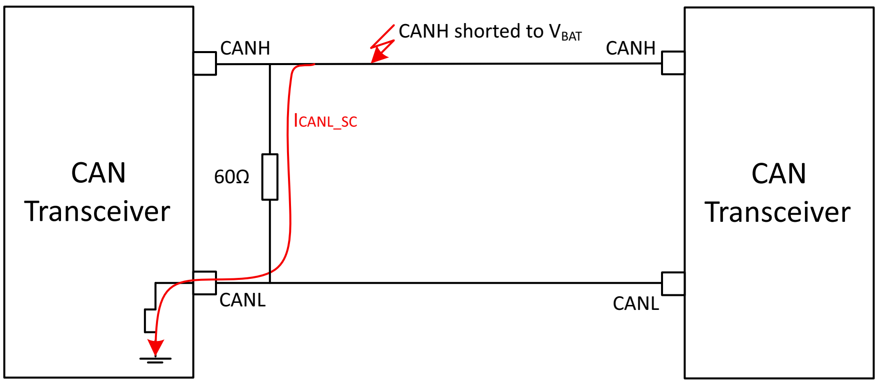

Figure 23 Current Flowing in Case of a Short Circuit CANH to V_{BAT}

8.4 TLE8250VSJ Junction Temperature

In Normal-operating mode highest power dissipation occurs with 50% duty cycle (D) at an ambient temperature of 150 °C:

$P_{NM,MAX} = D \times (I_{CC\_R} \times V_{CC,max}) + D \times (I_{CC\_D} \text{ x } V_{CC,max}) + (I_O \times V_{IO,max}) =$
$= 0.5 \times (4 \text{ mA} \times 5.5 \text{ V}) + 0.5 \text{ x } (60 \text{ mA} \times 5.5 \text{ V}) + (1.5 \text{ mA} \times 5.5 \text{ V}) = 184.25 \text{ mW}.$

Junction temperature increases due to power dissipation and depending on the package.

However, typical conditions are more like this: ambient temperature is below 150 °C, overall duty cycle is less than 50%, and supply voltages V_{CC} and V_{IO} have their typical values instead of maximum values.

Power dissipation is much lower for such typical conditions:

$P_{NM,AVG} = D \times (I_{CC\_R,Typ} \times V_{CC,AVG}) + D \times (I_{CC\_D,Typ} \text{ x } V_{CC,AVG}) + (I_{O,Typ} \times V_{IO,AVG}) =$
$= 0.9 \times (2 \text{ mA} \times 5 \text{ V}) + 0.1 \text{ x } (38 \text{ mA} \times 5 \text{ V}) + (1 \text{ mA} \times 3.3 \text{ V}) = 23.3 \text{ mW}.$

Table 8 Increase of Junction Temperature ΔT_j

Package	R_{thja} in K/W	ΔT_j in K	Conditions
PG-DSO-8	120	22.1	$P_{NM,MAX}$ = 184.25 mW; T_{amb} = 150 °C; 50% duty cycle; $V_{CC} = V_{CC,max}$; $V_{IO} = V_{IO,max}$
PG-DSO-8	120	2.8	$P_{NM,AVG}$ = 23.3 mW; T_{amb} = 85 °C; 10% duty cycle; $V_{CC} = V_{CC,typ}$; $V_{IO} = V_{IO,typ}$

Table 8 Increase of Junction Temperature ΔT_j

Package	R_{thja} in K/W	ΔT_j in K	Conditions
PG-DSO-8	120	6	Short Circuit CANH to GND 10% duty cycle;
PG-DSO-8	120	21.6	Short Circuit CANL to V_{BAT} 10% duty cycle;

If a short circuit occurs, then the TLE8250VSJ heats up. The higher the duty cycle, the higher the power dissipation and thermal shutdown can occur due to high temperature. The receiver is still enabled with only the transmitter disabled. The behavior is identical to Receive-only mode.

9 Thermal Simulation

This chapter provides simulation results forthermal resistance junction for T_A = -40°C, 25°C, 85°C, 105°C and 125°C. Top of package fixed to T_A : R_{th_jctop}. Bottom of package fixed to T_A: R_{th_jcbot}

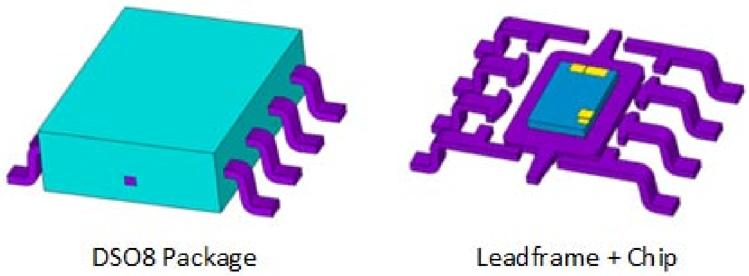

Figure 24 Package and Leadframe

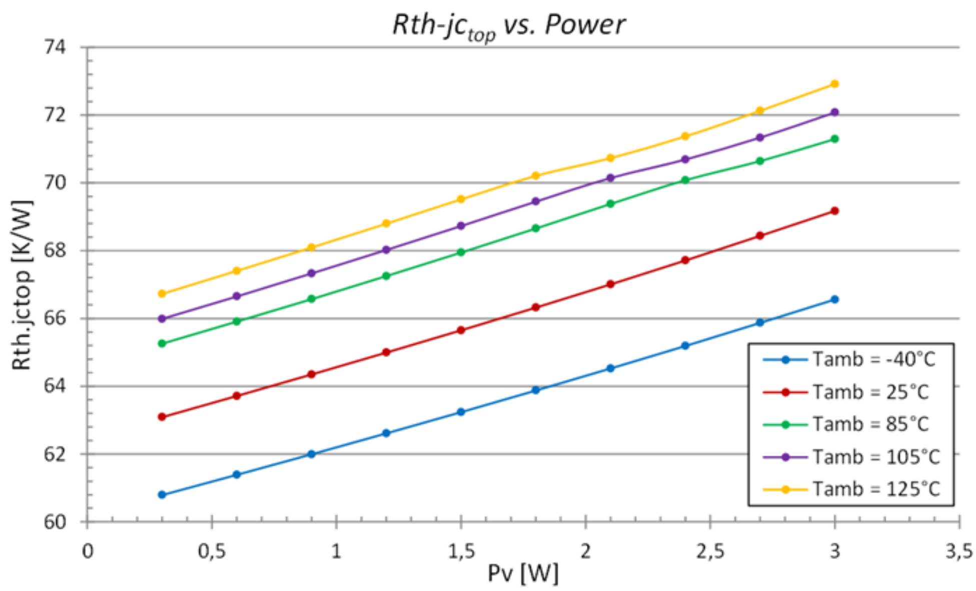

Figure 25 Simulation Result (R_{th_jctop} vs. Power)

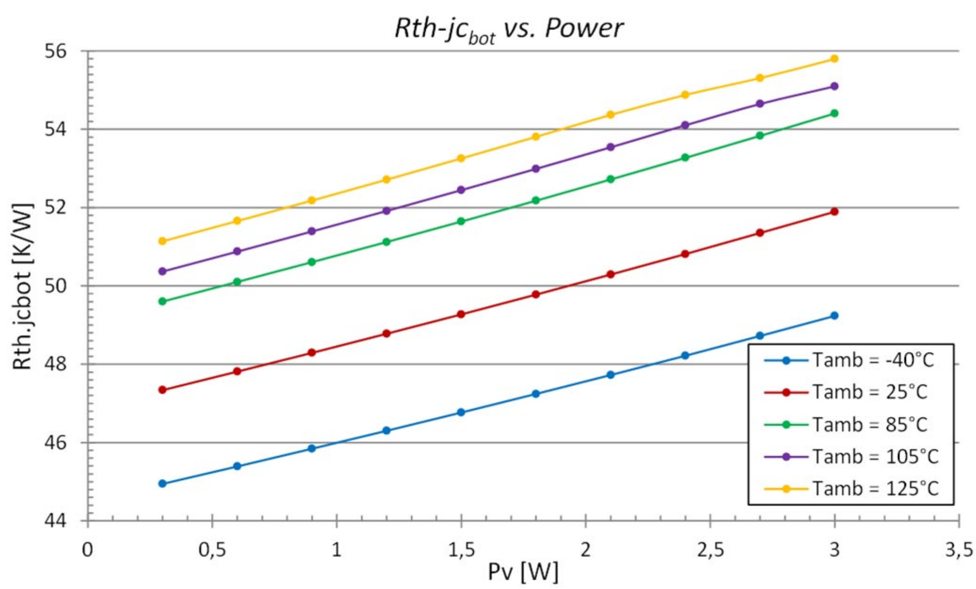

Figure 26 Simulation Result (R_{th_jcbot} vs. Power)

10 PCB Layout Recommendations for CAN FD

The following layout rules should be considered to achieve best performance of the transceiver and the ECU:

- TxD and RxD connections to microcontroller should be as short as possible.
- For each microcontroller the TxD driver output stage current capability may vary depending on the selected port and pin. The driver output stage current capability should be strong enough to guarantee a maximum propagation delay from µC port to transceiver TxD pin of less than 30ns.
- Place two individual 100nF capacitors close to V_{CC} and V_{IO} pins for local decoupling. Due to their low resistance and lower inductance compared to other capacitor types, it is recommended to use ceramic capacitors.
- If a common mode choke is used, it has to be placed as close as possible to the bus pins CANH and CANL.
- Avoid routing CANH and CANL in parallel to fast-switching lines or off-board signals in order to reduce noise injection to the bus.
- It is recommended to place the transceiver as close as possible to the ECU connector in order to minimize track length of bus lines.
- Avoid routing digital signals in parallel to CANH and CANL.
- CANH and CANL tracks should have the same length. They should be routed symmetrically close together with smooth edges.
- GND connector should be placed as close as possible to the transceiver.
- Avoid routing transceiver GND and microcontroller GND in series in order to reduce coupled noise to the transceiver. This also applies for high current applications, where the current should not flow through the GND line of transceiver and microcontroller in serial.
- Avoid routing transceiver V_{CC} supply and microcontroller V_{CC} supply in series in order to reduce coupled noise to the transceiver.
- Same dimensions and lengths for all wire connections from the transceiver to CMC and/or termination.
- In case an external ESD protection circuit is used, make sure the total capacitance is lower than 50pF. Use equal ESD protection for CANH and CANL in order to improve signal symmetry.
- For CAN FD application it is recommended to use a Common Mode Choke with 100µH impedance and a Split termination with a capacitance of 4.7nF in order to achieve excellent EME performance in automotive applications.

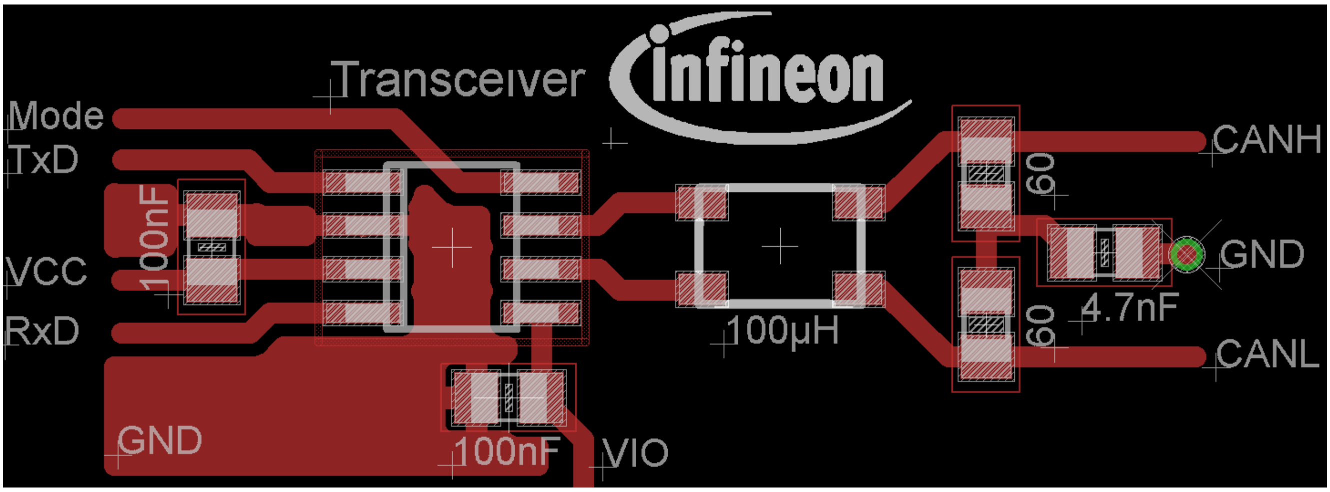

Figure 27 Example CAN transceiver PCB layout

11 Pin FMEA

This chapter provides an Pin FMEA (Failure Mode and Effect Analysis) for typical failure situations. Typical failure scenarios for dedicated pins of TLE8250VSJ are:

- Short circuit to battery voltageV_{BAT}
- Short circuit to supply voltage V_{CC}
- Short circuit to reference voltage V_{IO}
- Short circuit to PCB Ground GND
- Short circuit between neighbored pins
- Pin is not connected

The possible failures are classified according to possible failure effects (see **Table 9**)

Table 9 Classification of failure effects

Class	Possible effects
A	- Transceiver damaged - HS CAN bus affected
B	- No damage to transceiver - No CAN bus communication possible
C	- No damage to the transceiver - Bus communication possible - Affected node excluded from communication
D	- No damage to the transceiver - HS CAN bus communication possible - Reduced functionality of transceiver

Table 10 Pin FMEA Overview

Pin	Potential Failure	Potential Effects of Failure	Class
TxD	Short Circuit to GND	No damage to the transceiver. Transmitter is disabled after TxD dominant time-out. HS CAN bus communication blocked for t_{TXD_TO}. If failure does not recover transmitter will stay disabled and node cannot transmit data to the HS CAN bus. The receiver works as specified in the datasheet.	B
TxD	Short CIrcuit to V_{CC} / V_{IO}	No damage to the transceiver.	C
TxD	Short Circuit to V_{BAT}	Violation of absolute maximum ratings. Device gets damaged.	A
TxD	open	No damage to the transceiver. Due to the internal pull-up resistor the TxD stays “recessive”.	C
GND	Short Circuit to V_{CC} / V_{IO}	No damage to the transceiver. Transceiver stays unsupplied and is passive to the HS CAN Bus.	C
GND	Short Circuit to V_{BAT}	No damage to the transceiver. Transceiver stays unsupplied and is passive to the HS CAN Bus.	C
GND	open	No damage to the transceiver. Transceiver stays unsupplied and is passive to the HS CAN Bus.	C
V_{CC}	Short Circuit to V_{BAT}	Violation of absolute maximum ratings. Device gets damaged.	A

Table 10 Pin FMEA Overview

Pin	Potential Failure	Potential Effects of Failure	Class
V_{CC}	open	No damage to the transceiver. Transceiver stays unsupplied.	C
RxD	Short Circuit to V_{CC}	RxD remains “dominant”. If $V_{IO} < V_{CC}$ the device gets damaged due to violation of absolute maximum ratings.	A
RxD	Short Circuit to V_{IO}	RxD remains “dominant”. The RxD signal does not reflect the signal on the HS CAN bus. In this case the microcontroller is able to place a message on the CAN bus at any time and corrupts the CAN messages on the bus. The device is stressed if a “dominant” signal is driven. In this case the RxD output short circuits the V_{IO} to GND. The device gets damaged due to violation of absolute maximum ratings.	A
RxD	Short Circuit to V_{BAT}	Violation of absolute maximum ratings. Device gets damaged.	A
RxD	Short Circuit to GND	The device is stressed if a “recessive” signal is driven. In this case the RxD output short circuits the V_{IO} to GND. The device gets damaged due to violation of absolute maximum ratings.	A
RxD	open	No damage to the transceiver. Due to the internal pull-up resistor the RxD stays “recessive”. The RxD signal does not reflect the signal on the HS CAN bus. In this case the microcontroller is able to place a message on the CAN bus at any time and corrupts the CAN messages on the bus.	C
V_{IO}	Short Circuit to V_{CC}	No damage to the transceiver. Microcontroller might be destroyed.	D
V_{IO}	Short Circuit to V_{BAT}	Violation of absolute maximum ratings. Device gets damaged.	A
V_{IO}	Short Circuit to GND	No damage to the transceiver. Transceiver stays unsupplied and is passive to the HS CAN Bus.	C
CANL	Short Circuit to GND	No damage to the transceiver. Violation of bit timing parameters possible. Degraded EMC performance.	D
CANL	Short Circuit to V_{BAT}	No bus communication possible. No damage to the transceiver.	B
CANL	Short Circuit to V_{CC} / V_{IO}	No bus communication possible. No damage to the transceiver.	B
CANL	open	No damage to the transceiver. No bus communication possible.	B
CANL	Short Circuit to CANH	No damage to the transceiver. No bus communication possible.	B
CANH	Short Circuit to GND	No damage to the transceiver. No bus communication possible.	B
CANH	Short Circuit to V_{BAT}	No damage to the transceiver. Violation of bit timing parameters possible. Degraded EMC performance.	D
CANH	Short Circuit to V_{CC} / V_{IO}	No damage to the transceiver. Violation of bit timing parameters possible. Degraded EMC performance.	D
CANH	open	No damage to the transceiver. No bus communication possible	B
NEN	Short Circuit to GND	No damage to the transceiver. The Device will enter Normal-operating Mode.	D
NEN	Short Circuit to V_{BAT}	Violation of absolute maximum ratings. Device gets damaged.	A

Table 10 Pin FMEA Overview

Pin	Potential Failure	Potential Effects of Failure	Class
NEN	Short Circuit to V_{CC} / V_{IO}	If $V_{IO} < V_{CC}$ the device gets damaged due to violation of absolute maximum ratings. Device will enter Power-save Mode.	D
NEN	open	No damage to the transceiver. Device will enter Power-save Mode.	D

12 References

1) **Data Sheet TLE8250VSJ, HS CAN Transceiver, Infineon Technologies AG**

2) **White Paper - The CAN FD Physical Layer, Infineon Technologies AG**

3) **Infineon Automotive Transceivers Homepage**

Terms and Abbreviations

Table 11 Terms and Abbreviations

CAN	Controller Area Network
CMC	Common mode choke
CSMA/CA	Carrier Sense Multiple Access/ Collision Avoidance
EMC	Electromagnetic compatibility
EME	Electromagnetic emission
EMI	Electromagnetic interference
EOS	Electrical overstress
ESD	Electrostatic discharge
ESR	Equivalent Series Resistance
FD	Flexible Data Rate
“high”	logical high
“low”	logical low

13 Revision History

Revision	Date	Changes
1.3	2017-04-05	Added **Chapter 9** “Thermal Simulation” results for TLE8250VSJ in DSO-8 package
1.2	2016-12-27	Added power up sequence description in **Chapter 6.3** for of TLE8250VSJ
1.1	2016-07-20	**Chapter 12**: Added link to Data Sheet of TLE8250VSJ
1.0	2016-07-15	Application Note created

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