Application Note
TLE9251V

About this document

Scope and purpose

This document provides application information for the transceiver TLE9251V from Infineon Technologies AG as Physical Medium Attachment within a Controller Area Network (CAN).

This document contains information about:

- TLE9251V summary description (see **Chapter 1**)
- Infineon 5Mbit/s CAN FD transceiver products (see **Chapter 1.3**)
- Example CAN applications (see **Chapter 2**)
- CAN FD parameters explanation according to ISO11898-2: 2016 (see **Chapter 3**)
- Protocol Changes: Classical CAN and CAN Flexible Data Rate (see **Chapter 3.3**)
- Detailed TLE9251V pin description (see **Chapter 4**)
- Power supply concepts (see **Chapter 5**)
- Current consumption in Stand-by Mode (see **Chapter 5.5**)
- Mode control hints (see **Chapter 6**)
- Quiescent current savings (see **Chapter 6**)
- Bus Wake-Up Pattern (WUP) explanation (see **Chapter 6.4**)
- Fail safe features and behavior e.g. short circuit (see **Chapter 7**)
- PCB recommendations for CAN FD applications (see **Chapter 8**)
- TLE9251V footprint dimensions (see **Chapter 9**)
- Pin FMEA (see **Chapter 10**)

This document refers to the data sheet of the Infineon Technologies AG CAN Transceiver TLE9251V.

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 TLE9251V Description

The transceiver TLE9251V represents the physical medium attachment, interfacing the CAN protocol controller to the CAN transmission medium. The transmit data stream of the protocol controller at the TxD input is converted by the CAN transceiver into a bus signal. The receiver of the TLE9251V detects the data stream on the CAN bus and transmits it via the RxD pin to the protocol controller.

1.1 Major Features

The main features of the TLE9251V are:

- Baud-rate up to 5 Mbit/s supporting CAN Flexible Data Rate
- Optimized very low Electromagnetic Emission (EME) and high Electromagnetic Immunity (EMI)
- Excellent ESD performance according to HBM (+/-8 kV) and IEC (+/-11 kV)
- Very low current consumption in Stand-by mode
- Bus wake-up pattern (WUP) capability in Stand-by mode with optimized filter time
- Supply voltage range 4.5 V to 5.5 V
- V_{IO} input for voltage adaption to the microcontroller interface (3.3V & 5V)

1.2 Mode Description

TLE9251V supports three different modes of operation, which are selected by the mode pin STB:

Table 1 Description of Modes

Mode	Use Cases
Normal-operating mode	• Transmit and receive data on the HS CAN bus
Forced-receive-only mode	• Same behavior as Receive-only mode. • Fail-safe mode for V_{CC} undervoltage condition. • By switching off V_{CC} additional leakage current can be saved and ECU current consumption can be reduced. This can be used for Pretended Networking to set ECU and microcontroller to low-power mode, waiting for a specific message to switch to Normal-operating mode.
Stand-by mode	• Sets the ECU to a low-power mode in permanently supplied networks. • Minimized current consumption. • TLE9251V can still detect a bus wake-up and wake up the ECU.

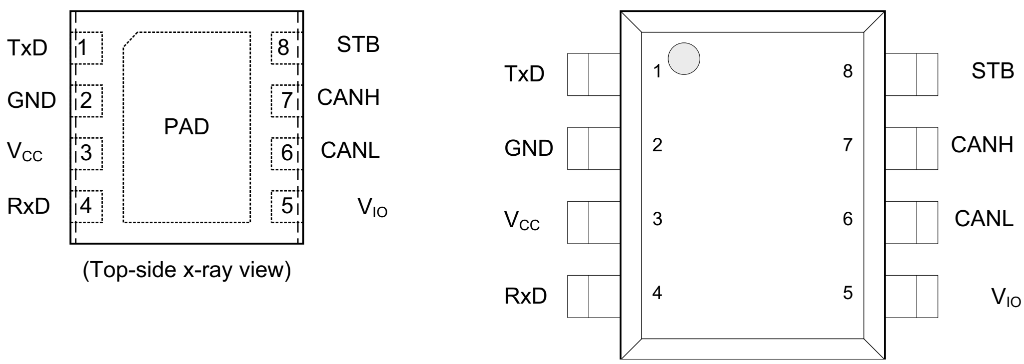


Figure 1 Pin Configuration of the TLE9251V

1.3 Overview on Infineon 5Mbit/s CAN FD Products

TLE9251V is part of the 8-pin CAN FD TLE9250 / TLE9251 - Family. This family includes five different versions:

- TLE9250SJ / TLE9250LE
- TLE9250VSJ / TLE9250VLE
- TLE9250XSJ / TLE9250XLE
- TLE9251VSJ / TLE9251VLE
- TLE9251SJ/ TLE9251LE

The five different versions cover various application possibilities. For each application an adequate solution can be chosen according to the application requirements. Differences between the versions are features like:

- microcontroller voltage adaption: V_{IO}-Feature (see **Chapter 5.4**)
- Different mode of operation (Power-save mode, Receive-only mode, Stand-by mode)
- Bus Wake-up capability (see **Chapter 6.4**)

An overview of the different features is included in **Table 2**. All version are CAN FD capable up to 5Mbit/s.

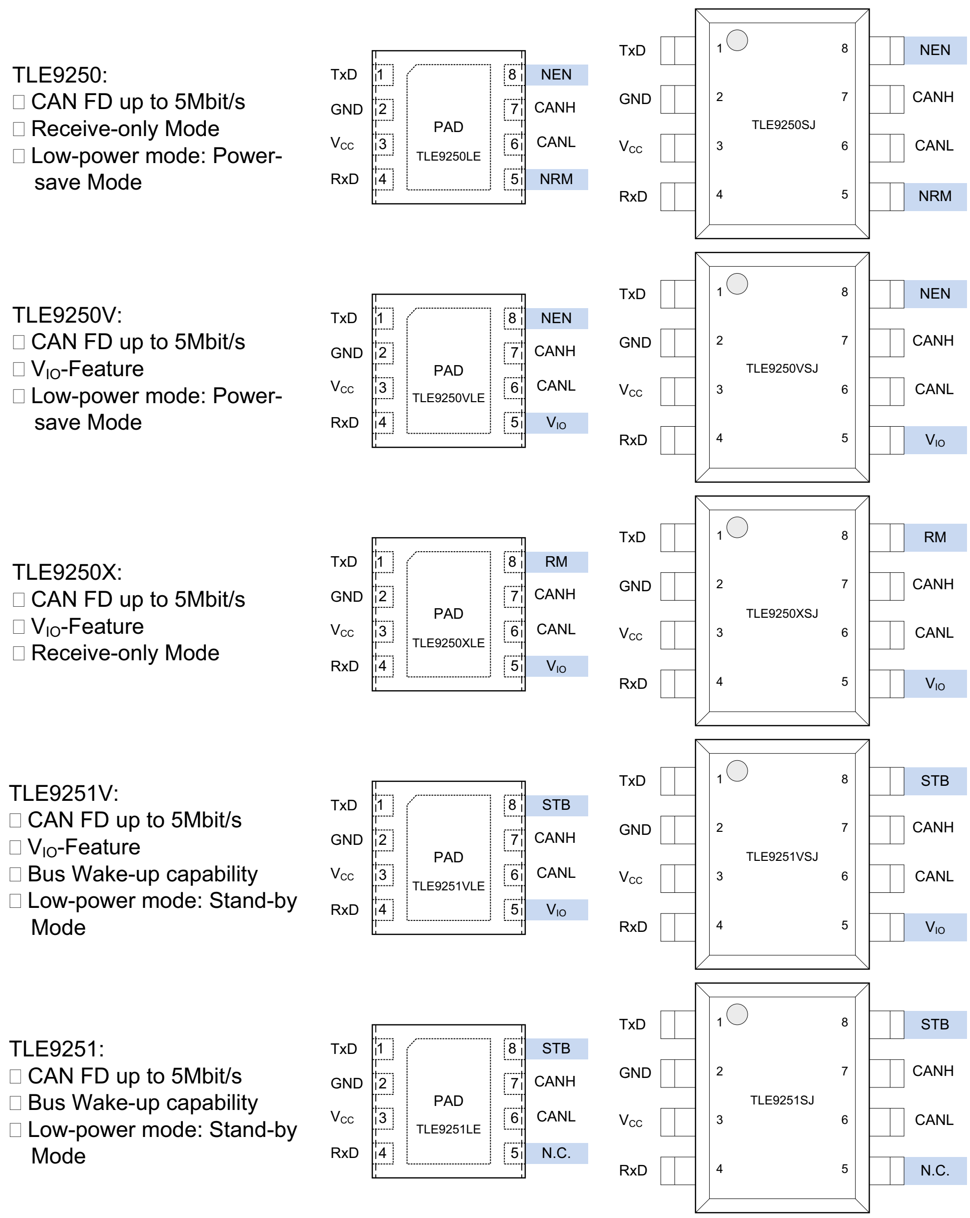


Figure 2 TLE9250 / TLE9251 - Family Overview

Table 2 Feature Overview of Infineon 5Mbit/s CAN FD Transceiver

CAN FD Transceiver	Number of Pins	Modes					Fail-safe Features				Wake-up		NERR Diagnostics Output	SPI	INH output pin	Host Interface voltage range	Partial Networking
		Normal-operating Mode	Receive-only Mode	Stand-by Mode	Power-save Mode	Sleep Mode	TxD Dominant Time-out	Undervoltage detection	Over Temperature	Short CIrcuit Protection	Bus Wake-up	Local Wake-up					
TLE9250SJ / TLE9250LE	8	✓	✓	–	✓	–	✓	✓	✓	✓	–	–	–	–	–	4.5 - 5.5V	–
TLE9250VSJ / TLE9250VLE	8	✓	–	–	✓	–	✓	✓	✓	✓	–	–	–	–	–	3.0V - 5.5V	–
TLE9250XSJ / TLE9250XLE	8	✓	✓	–	–	–	✓	✓	✓	✓	–	–	–	–	–	3.0V - 5.5V	–
TLE9251VSJ / TLE9251VLE	8	✓	–	✓	–	–	✓	✓	✓	✓	✓	–	–	–	–	3.0V - 5.5V	–
TLE9251SJ / TLE9251LE	8	✓	–	✓	–	–	✓	✓	✓	✓	✓	–	–	–	–	4.5 - 5.5V	–
TLE9252VSK / TLE9252VLC	14	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	–	✓	3.0V - 5.5V	–
TLE9255WSK / TLE9255WLC	14	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	–	✓	✓	3.0V - 5V	✓

1.4 TLE925x-Family Pin-out Compatibility

The TLE925x-Family is pin-out and functional compatible to existing Infineon CAN transceivers (see **Figure 3**):

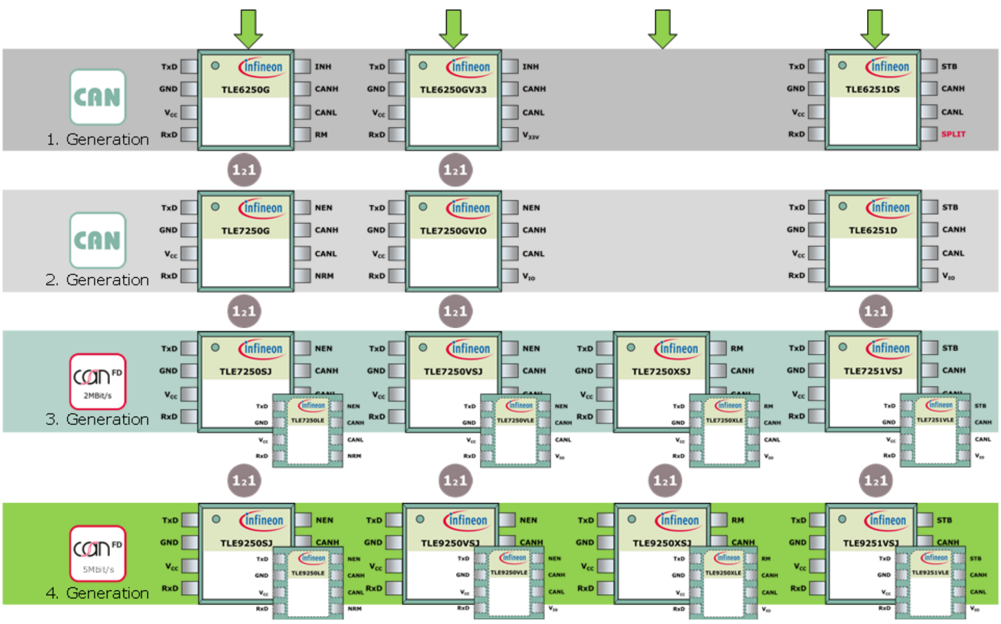


Figure 3 TLE925x-Family Pin-out Compatibility

2 CAN (Controller Area Network) Example 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 required.

Typically an ECU consists of:

- power supply
- microcontroller with integrated CAN protocol controller
- CAN transceiver
- actuators and sensors

The CAN protocol uses a lossless bit-wise arbitration method for conflict resolution. This requires all CAN nodes to be synchronized. The complexity of the network can range from a point-to-point connection up to hundreds of nodes. A simple network concept using CAN is shown in **Figure 4**.

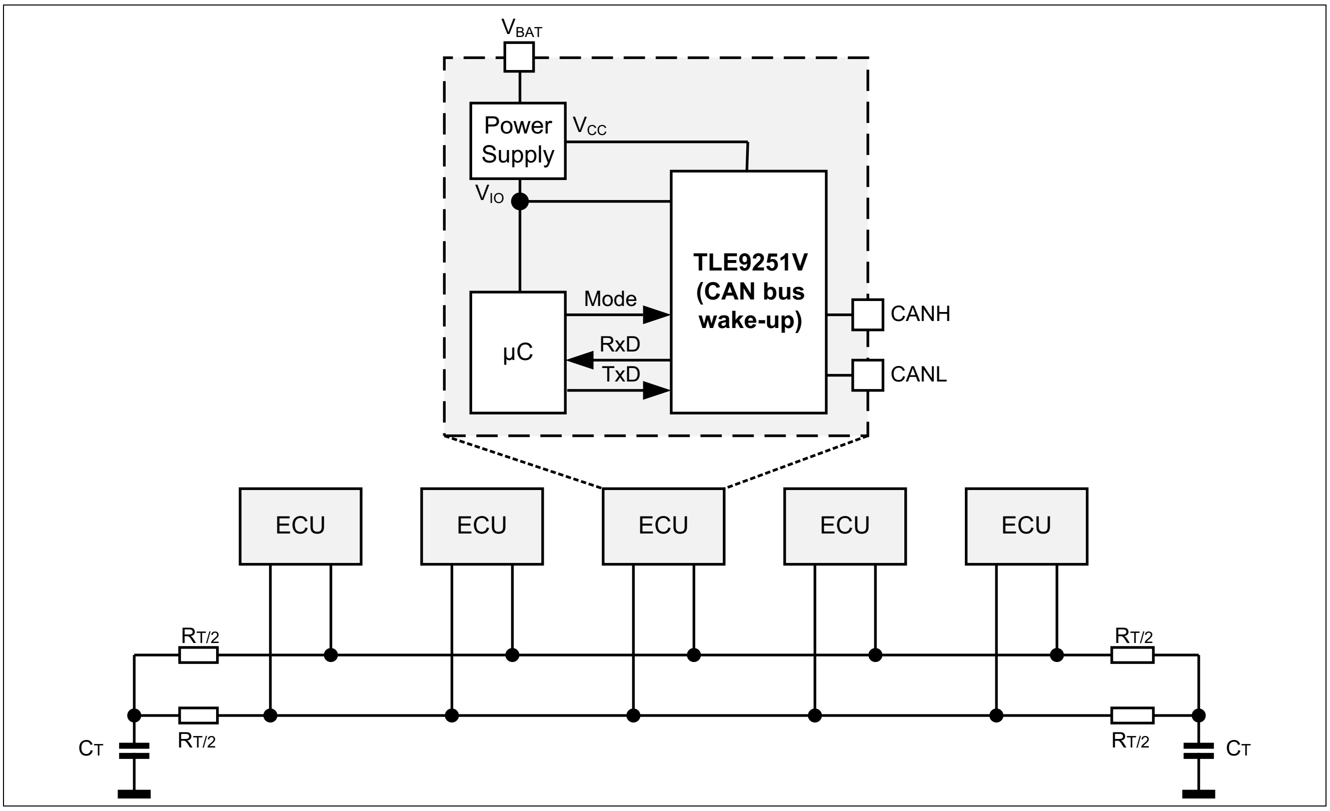


Figure 4 ECU Application Example with TLE9251V

The CAN bus physical layer can have the following states (see **Figure 5**):

- dominant:
  - TxD pin set to “low” generates differential voltage on CANH and CANL line
  - voltage at CANH changes towards V_{CC}
  - voltage at CANL changes towards GND
- recessive:
  CANH and CANL are biased to $V_{CC}/2$ via an internal termination resistor

See **Table 3** for voltage levels specified for dominant and recessive state.

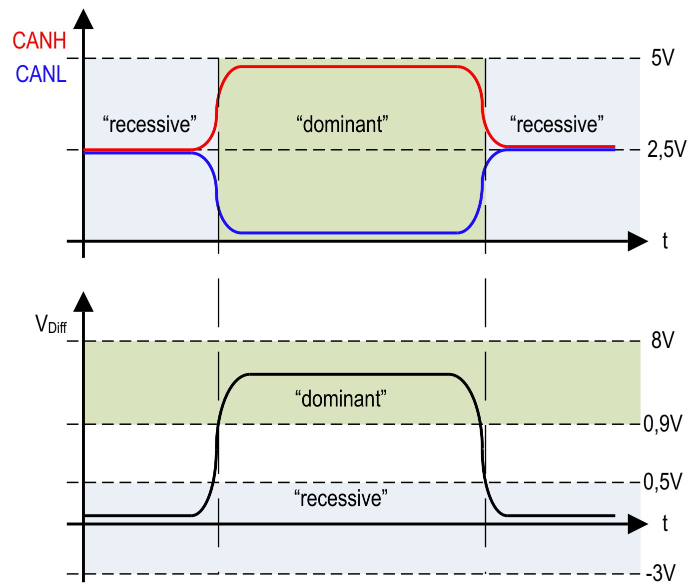


Figure 5 Voltage Levels according to ISO 11898-2 (Edition 2016)

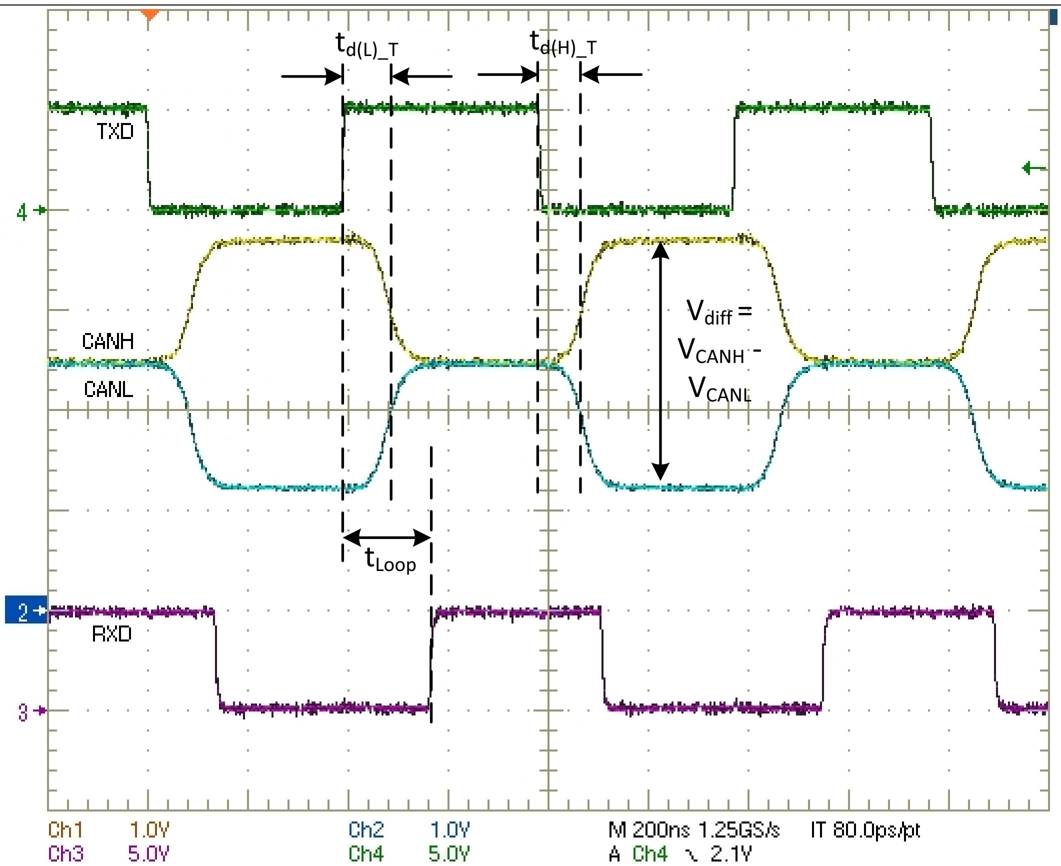


Figure 6 Example measurement CAN Bus Signals with TLE9251V

The CAN physical layer is described in ISO 11898-2: 2016. The CAN transceiver TLE9251V fulfills all parameters defined in ISO 11898-2: 2016. Hence TLE9251V is fully ISO11898-2: 2016 compliant.

Table 3 Voltage Levels according to ISO 11898-2 (Edition 2016)

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	–

In Vehicle Network application

TLE9251V offers improved loop delay symmetry to support CAN FD data frames up to 5MBit/s. For permanently supplied ECUs (Clamp 30) as well as for partially supplied ECUs (Clamp 15) the TLE9251V is suitable. Depending on the requirements of car manufacturers, modules can either be permanently supplied or unsupplied when the car is parked. The main purpose for unsupplied modules is saving battery energy.

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. In Clamp 30 applications the most important feature is very low current consumption in order to prevent the battery from discharging. TLE9251V offers the Stand-by mode with optimized very low current consumption and bus wake-up capability. If bus communication is monitored on the HS CAN bus, then the TLE9251V indicates this wake-up event on the RxD pin. The wake-up event wakes up the microcontroller.

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.

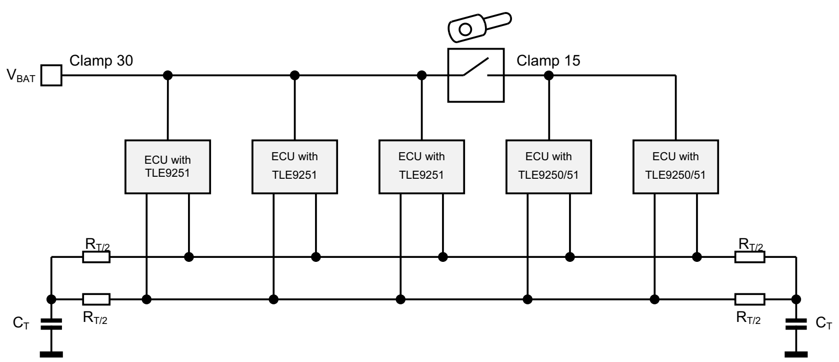


Figure 7 CAN with ECUs Using TLE9251V

3 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 in order to ensure correct operation at higher frequencies..

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

3.1 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 won the arbitration, during 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 5 Mbit/s.

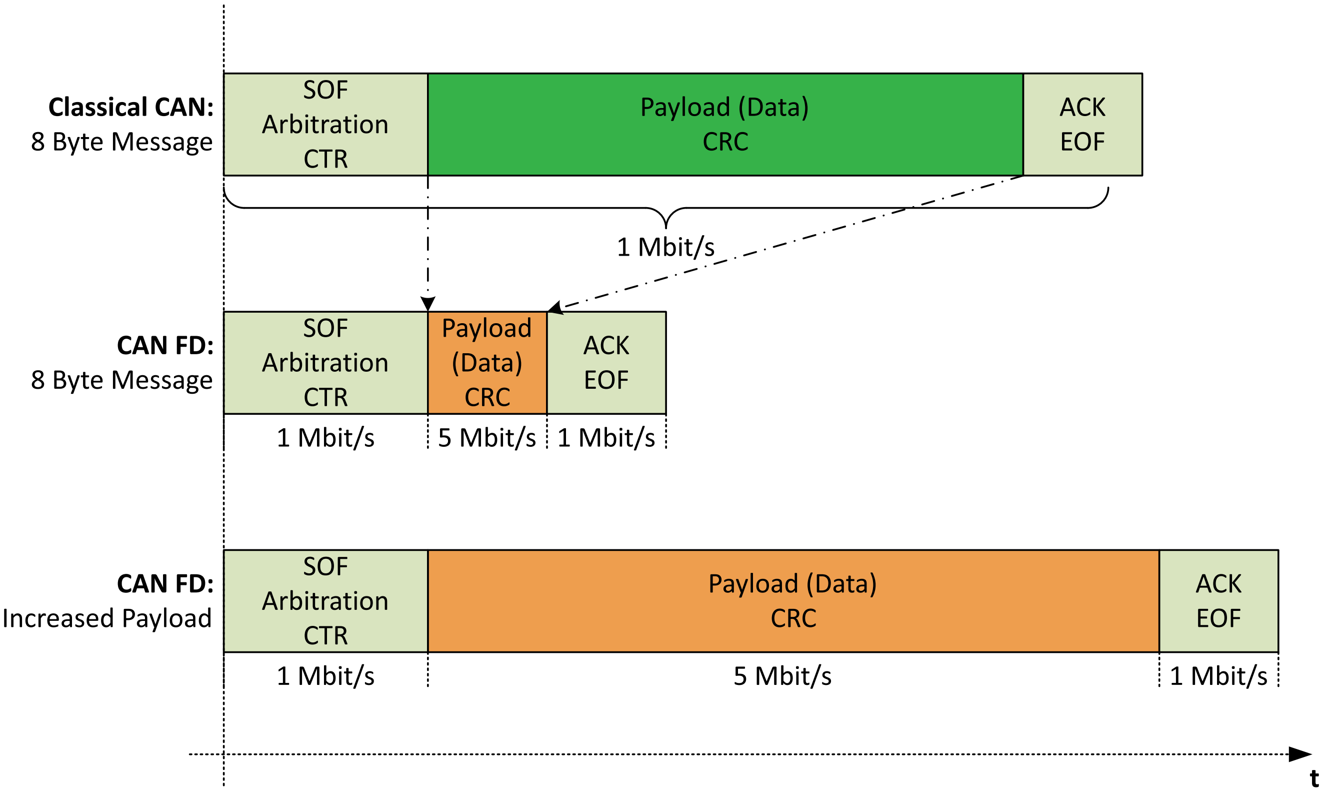


Figure 8 Classical CAN Data Rate and CAN Flexible Data Rate

3.2 TLE9251V CAN FD Parameters

The TLE9251V from Infineon is the perfect suitable match for CAN FD networks. TLE9251V fulfills the CAN FD parameters according to ISO 11898-2 (Edition 2016) for 2Mbit/s and 5Mbit/s in order to enable smooth and safe usage within applications.

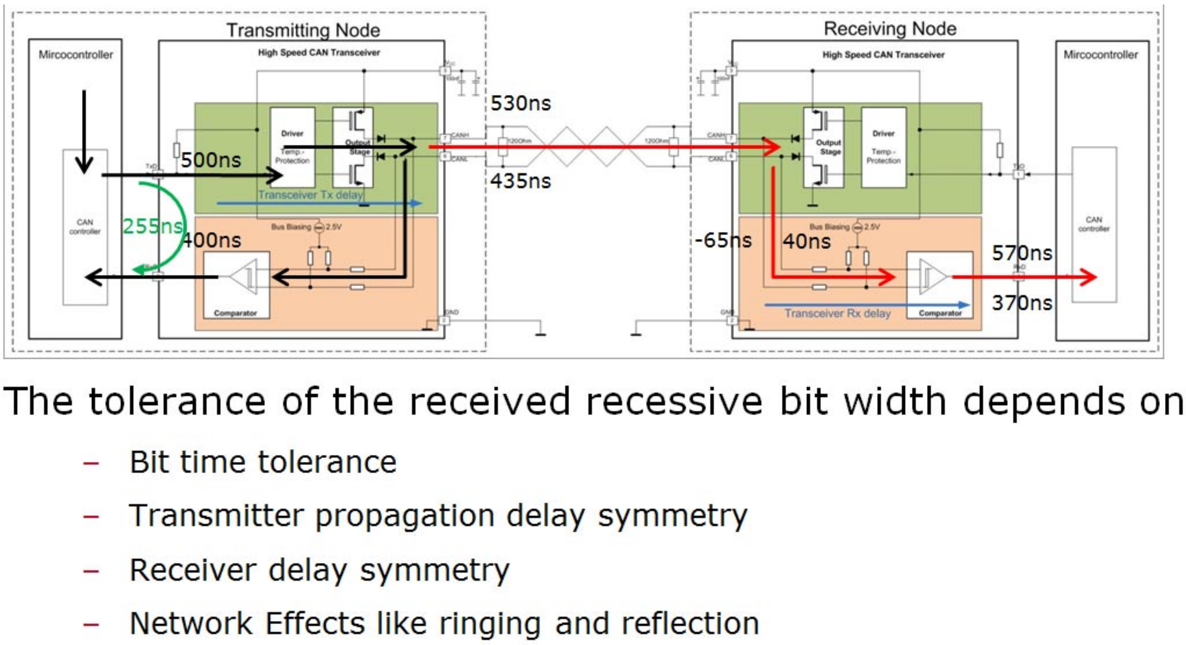


Figure 9 Propagation Delay Effects in CAN Networks

Table 5 Specification of TLE9251V

Specification	**CAN FD Specification ISO 11898-2: 2016**		
Parameter	min	max	Unit
Received recessive bit width on transmitting node (2Mbit/s)	400	550	ns
Transmitter delay symmetry (2Mbit/s)	435	530	ns
Receiver delay symmetry (2Mbit/s)	-65	+40	ns
Received recessive bit width on receiving node (2Mbit/s)	370	570	ns
Received recessive bit width on transmitting node (5Mbit/s)	120	220	ns
Transmitter delay symmetry (5Mbit/s)	155	210	ns
Receiver delay symmetry (5Mbit/s)	-40	+15	ns
Received recessive bit width on receiving node (5Mbit/s)	115	225	ns

TLE9251V has optimized timing parameters for CAN Flexible Data Rate 2Mbit/s and 5Mbit/s, which adds additional safety margin for network effects like ringing effects and network propagation delay.

3.3 Protocol Changes of CAN FD

Using CAN Flexible Data Rate also requires the usage of the ISO Frame Format CAN Flexible Data Rate Protocol for a save application. The Protocol Changes from Classical CAN Frame to CAN FD Frame Format implies:

- Increased payload of up to 64bytes per frame
- Increased data rate up to 5Mbit/s
- Extended Identifier up to 29 bits
- Extended Cyclic Redundancy Check (CRC) of up to 21 bits
- New Control Field bits (Flexible Data Rate Frame Indicator Bit, Bit Rate Switch, Remote Request Substitution Bit, Error State Indicator Bit)

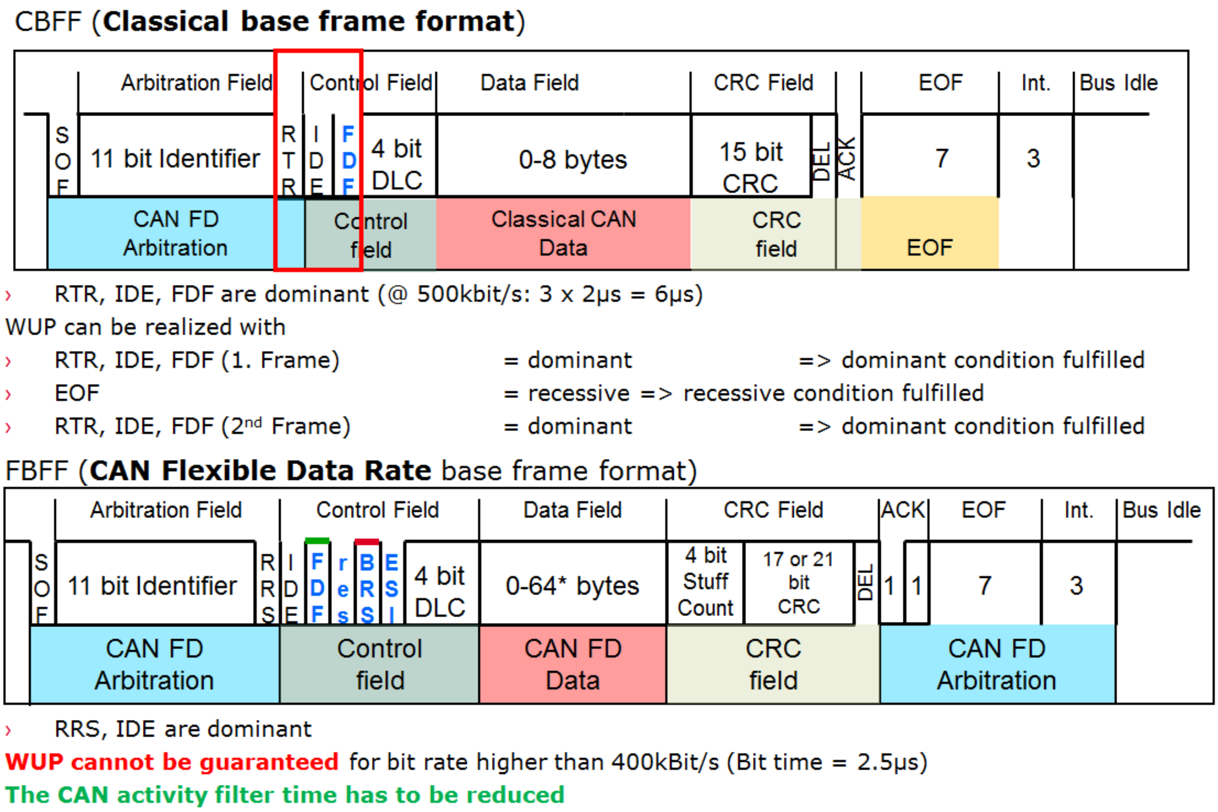


Figure 10 Protocol Changes Classical CAN Frame to CAN FD Frame

This protocol change from Classical CAN to CAN Flexible Data-Rate has significant impact on the wake-up behavior of CAN transceivers. For Classical CAN the CAN filter activity has been define as 0.5µs < t_{Filter} < 5µs in the past. But a device with a CAN wake-up filter t_{Filter} > 2µs cannot ensure a reliable and robust wake-up of the transceiver in low-power Mode for 500kbit/s arbitration rate.

In order to ensure a wake-up with every possible Frame Format on the HS CAN Bus Infineon's new TLE9251V has improved and optimized wake-up filter time specified as 0.5µs < t_{Filter} < 1.8µs. A minimum of t_{Filter} > 0.5µs offers very high robustness against transients and noise on the HS CAN Bus. A maximum of t_{Filter} < 1.8µs ensures a wake-up indication for every possible Classical CAN and CAN FD Frame.This unique wake-up filter timing ensure reliable and robust wake-up behavior in CAN FD applications (see **Figure 11**).

Table 6 TLE9251V Wake-up filter specification

Description	Parameter	min	max	Unit
TLE9251V optimized wake-up filter specification according to ISO11898-2: 2016	t_{Filter}	0.5	1.8	µs

CAN FD

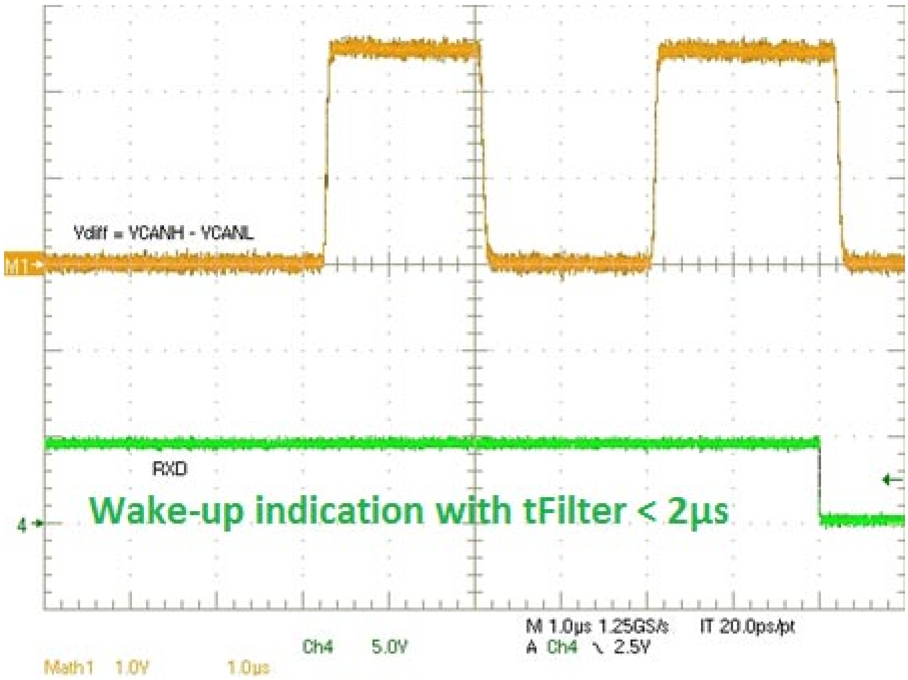


Figure 11 Wake-up indication of TLE9251V in Stand-by Mode with short bit timing

3.4 Baud Rate versus Bus Length

Table 7 Recommended Baud Rate versus Bus Length

Maximum 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. 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 Pin Description

This chapter describes TLE9251V input and output pins in more detail.

4.1 V_{IO} Pin

The V_{IO} pin is needed for the operation with a microcontroller to match the voltage level between microcontroller and transceiver. It can also be used to decouple microcontroller and transmitter supply. Place a 100 nF capacitor directly at V_{IO} pin.

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)
- supply of the wake receiver (see **Chapter 6.6**)
- supply of the normal receiver (see **Chapter 6.7**)
- voltage adaption for external microcontroller (3.0 V < V_{IO} < 5.5 V)

As long as V_{IO} is supplied ($V_{IO} > V_{IO\_UV}$) 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 TLE9251V can work with various microcontroller supplies. If V_{IO} is available, then both transceiver and microcontroller are fully functional. Below $V_{IO} < V_{IO\_UV}$ the TLE9251V is in Power On Reset state. To enter Normal-operating mode $V_{IO} \geq V_{IO\_UV}$ is required.

4.2 V_{CC} Pin

The V_{CC} pin supplies the transmitter output stage. Place a 100 nF capacitor directly at V_{CC} pin.

Table 8 Transmitter state depending on V_{CC}

V_{CC}	Transmitter state	Note
$V_{CC} < V_{CC\_UV}$	disabled	3.8 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	–
5.5 V < V_{CC} < 6 V	enabled; parameters may be outside the specified range	–
V_{CC} > 6 V	damage of TLE9251V possible	–

4.3 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.

4.4 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 has impact on the timing symmetries and delay timings, especially in high data rate applications with CAN FD.

4.5 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 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 7.1**). 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.

4.6 STB Pin

The STB pin sets the mode of TLE9251V and is usually directly connected to an output port of a microcontroller. If the mode pin is not connected and TLE9251V is supplied by V_{IO}, then the device enters Stand-by mode due to the internal pull-up resistor to V_{IO}. The purpose of the Stand-by mode is to reduce current consumption, while the TLE9251V can detect a bus wake-up. To put the device into Normal-operating mode, the STB pin must be set to “low”. The user can deactivate transmitter of TLE9251V either by setting the STB pin to “high” 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. **Table 9** shows mode changes by the STB pin, assuming $V_{IO} > V_{IO\_UV}$. **Chapter 1** describes features and modes of operation.

Table 9 Mode Selection by STB

Mode of operation	STB	V_{CC}	Note	Low-power Receiver	Receiver	Transmitter
Stand-by mode	“high”	“X”[1)]	TLE9251V monitors the bus for a valid wake-up pattern and indicates wake-up detection on the RxD output pin.	enabled	disabled	disabled
Forced-receive-only mode	“low”	$< V_{CC\_UV}$	Same as Receive-only Mode	enabled	disabled	disabled
Normal-operating mode	“low”	$> V_{CC\_UV}$	–	disabled	enabled	enabled

1) “X”: don’t care

4.7 CANH and CANL Pins

CANH and CANL are the CAN bus input and output pins. The TLE9251V 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 3**. Due to the excellent ESD robustness on CANH and CANL no external ESD components are necessary to fulfill OEM requirements. ESD robustness:

- HBM (Human Body Model): +/-8kV
- IEC 61000-4-2 “Gun Test”: +/- 11kV (see EMC Test Report Nr. 01-07-2017 and Nr. 06-08-2017)

5 Transceiver Supply

The internal logic of TLE9251V is supplied by the V_{IO} pin. The V_{CC} pin 5 V supply is used to create the CANH and CANL signal. The transmitter output stage is supplied by the V_{CC} pin. The receiver is supplied by the V_{IO} supply pin. This chapter describes aspects of power consumption and voltage supply concepts of TLE9251V.

5.1 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**

Refer to **Infineon Linear Voltage Regulators** for voltage regulator portfolio, data sheets and app notes.

5.2 External Circuitry on V_{CC} and V_{IO}

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 on the PCB. During sending a dominant bit to the HS CAN bus, current consumption of TLE9251V is higher than during sending a recessive bit. Data transmission changes the load profile on V_{CC}, which may reduce the load regulation of V_{CC}. If several CAN transceivers are connected in parallel and are supplied by the same V_{CC} and/or V_{IO} power supply (for example LDO), then the impact on the load regulation of V_{CC} is even stronger. It is required to place a 100 nF capacitor directly at V_{CC} and V_{IO} pin. Without 100nF decoupling capacitance higher EME has to be expected. Due to their low ESR ceramic capacitors are recommended. The output of the V_{CC} and V_{IO} power supply must be stabilized by a capacitor in the range of 1 to 50 µF, depending on the load profile.

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

As TLE9251V 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 TLE9251V. There is no limitation for the start-up sequence for TLE9251V:

- Scenario 1: If V_{IO} is supplied first, the internal state machine will start working for $V_{IO} > V_{IO\_UV}$. Then the mode of operation can be changed by the mode selection pins STB. The transmitter of TLE9251V 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, then only the transmitter output stage is supplied. But as V_{IO} is not yet supplied the output of the transmitter is High-Z (disabled, in order to not disturb the bus communication).
- Scenario 3: If V_{CC} and V_{IO} are connected to the same supply voltage (V_{supply} = 5V), the state machine will start working for $V_{Supply} > V_{IO\_UV}$ (max. 3.0V) and the transmitter will be enabled if $V_{Supply} > V_{CC\_UV}$ (max. 4.5V).

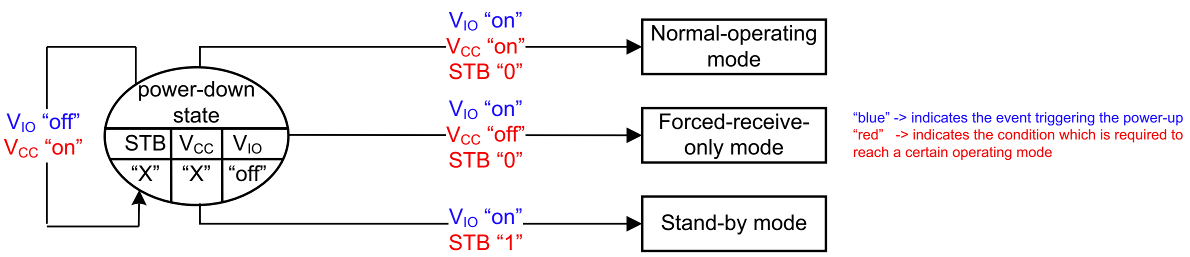


Figure 12 Power-up Scenarios for TLE9251V

5.4 V_{IO} Feature

TLE9251V 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 of TLE9251V. Depending on the voltage supply of the microcontroller, TLE9251V can operate with the V_{IO} reference voltage input within the voltage range from 3.0 V to 5.5 V. The V_{CC} pin supplies the transmitter of TLE9251V. 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 order to reduce quiescent current (see **Chapter 6.6**, **Chapter 6.7**).

5.4.1 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 TLE9251V 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 TLE9251V to operate with a microcontroller. With the V_{IO} reference voltage input the TLE9251V can operate from 3.0 V to 5.5 V. If the microcontroller uses V_{CC} = 5 V supply, then V_{IO} supply has to be connected to V_{CC} supply. The V_{IO} input must be connected to the supply voltage of the microcontroller (see **Figure 13**).

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.

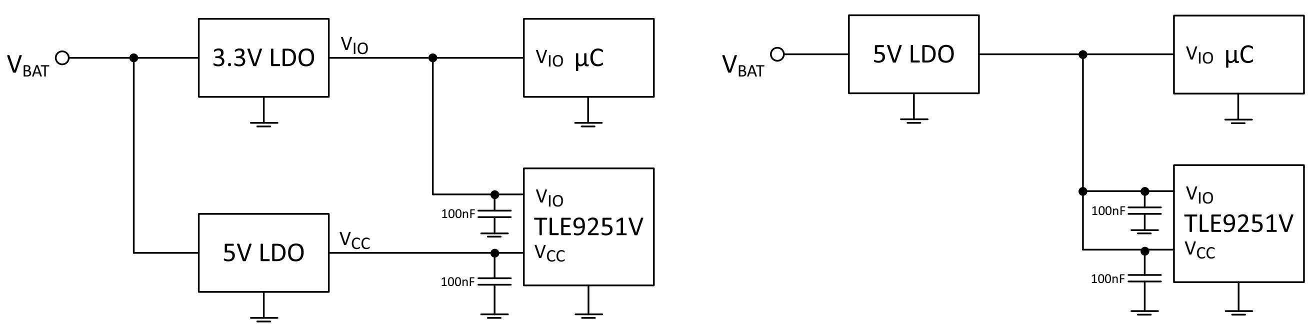


Figure 13 3.3 V Power Supply Concept

5.5 Current Consumption

Current consumption depends on the mode of operation:

- Normal-operating mode:
  Maximum current consumption of TLE9251V on the V_{CC} supply is specified as 60 mA in dominant state and 4 mA in recessive state. Maximum current consumption of TLE9251V on the V_{IO} supply is specified as 1.5 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 TLE9251V consumes worst case maximum:
  $I_{CC\_AVG} = (I_{CC\_REC} + I_{CC\_DOM}) / 2 + I_{IO} = 32.75$ mA
  Typically the current consumption is less than 15 mA.
- Receive-only mode and Forced-receive-only mode:
  In Receive-only mode the TLE9251V has a worst case maximum current consumption of I_{ROM} = 1.5 mA. Typically the current consumption is less than 800 µA.
- Stand-by mode:
  In Stand-by mode most of the functions are turned off. With TLE9251V it is possible to switch off V_{CC} supply to save additional quiescent current, while the receiver can still wake up the microcontroller via a bus wake-up (see **Chapter 6.6**). The maximum current consumption is specified as $I_{IO,max}$ = 15 µA for T < 125 °C.

5.6 Loss of Battery (Unsupplied Transceiver)

When TLE9251V 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, TLE9251V behaves like a 1 MΩ resistor towards the bus. Therefore the device perfectly fits applications that use both Clamp 15 and Clamp 30.

5.7 Loss of Ground

If loss of ground occurs, then the transceiver is unsupplied and behaves like in unpowered state.

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.

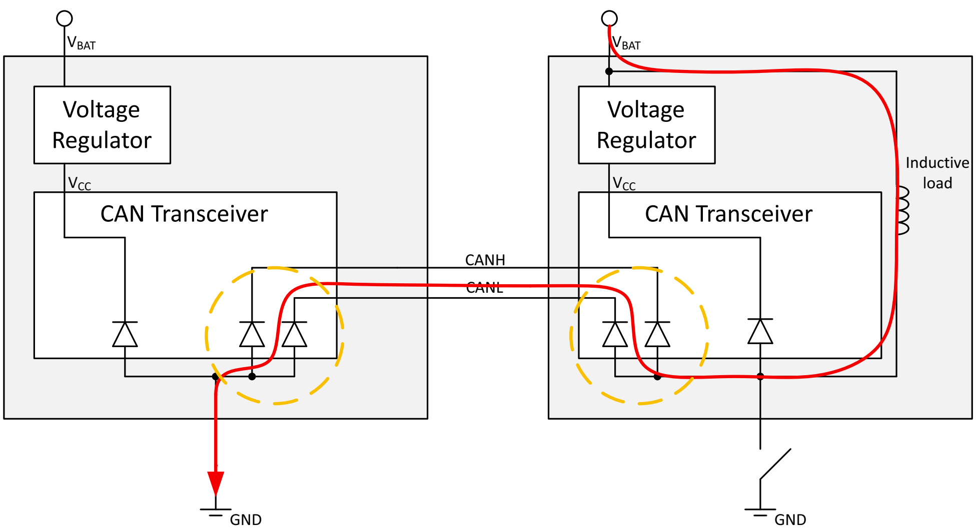


Figure 14 Loss of GND with Inductive Load

5.8 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. 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 works. Only the difference voltage (CAN_H - CAN_L) is relevant for the receiver. shows a typical CAN signal with a DC ground shift of +2V.

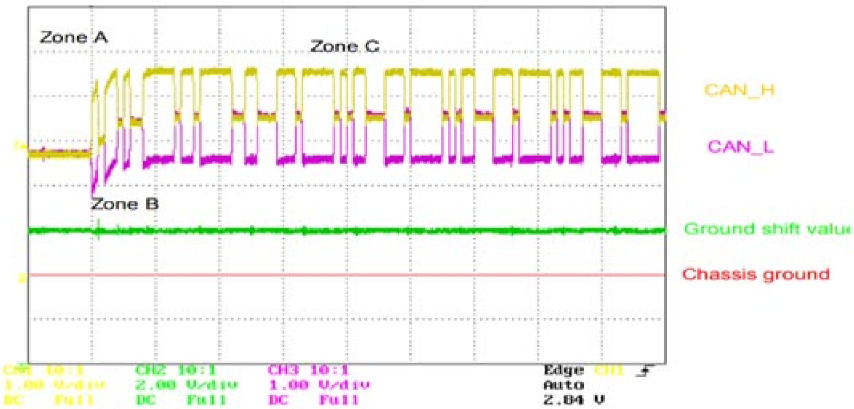


Figure 15 DC ground shift signal

Zone A : Shows the recessive voltage of the system, so close to the nominal recessive value of 2.5V

Zone B : When the transmitter starts to communicate the signal grows quickly.

Zone C : The communication is stabilized, and the recessive voltage reaches the value, as computed on equation below. 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

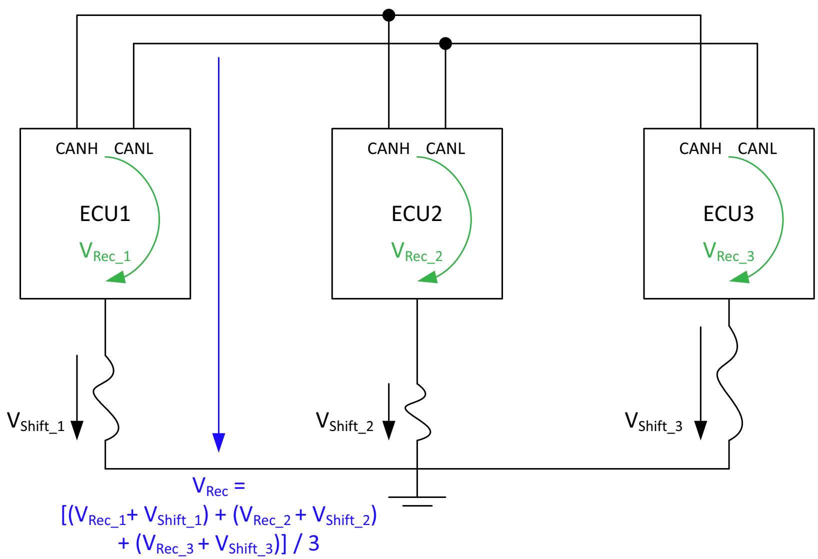


Figure 16 Ground Shift on three nodes (system view)

6 Mode Control

The modes of the TLE9251V are controlled by the pin STB and by transmitter voltage V_{CC}.

6.1 Mode Change by STB

The mode of operation is set by the mode selection pin STB. By default the STB input pin is "high" due to the internal pull-up current source to V_{IO}.
The TLE9251V can enter Stand-by mode independently of the status of V_{CC}. In order to change the mode to Normal-operating mode, STB must be switched to "low" and V_{CC} must be available.

6.2 Mode Change Delay

The HS CAN transceiver TLE9251V 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. During the mode change from Stand-by mode to a non-low power mode the receiver and/or transmitter is enabled (see). During the period t_{Mode} the RxD output pin is 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 TLE9251V releases the RxD output pin. **Figure 17** shows this scenario. For wake-up pattern (WUP) detection and mode change please also see **Chapter 6.5**.

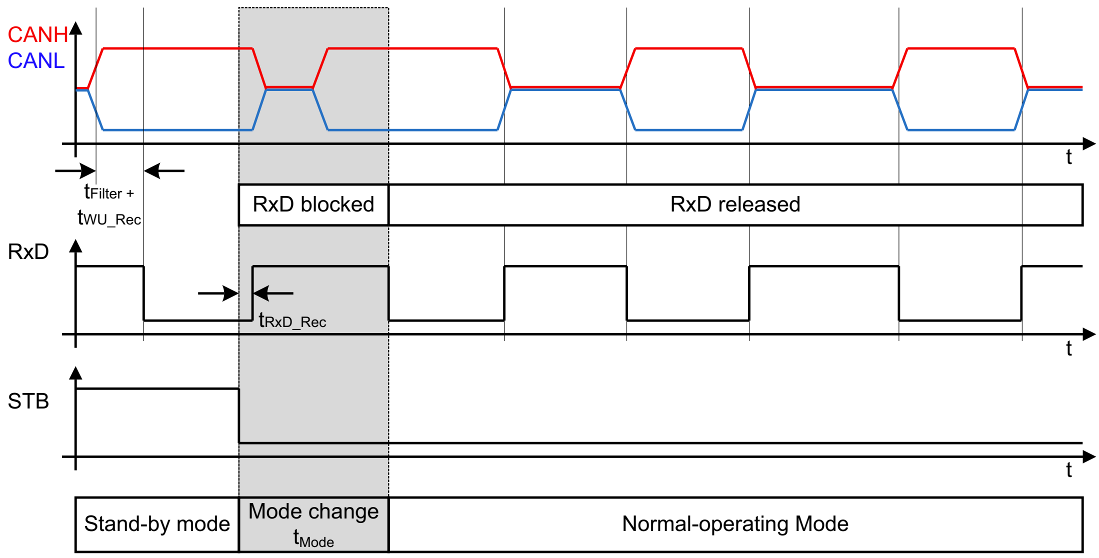


Figure 17 RxD Behavior during Mode Change

The RxD output pin is not blocked nor be set to "high" during the following mode changes:

- Normal-operating mode → Forced-receive-only mode
- Forced-receive-only mode → Normal-operating mode

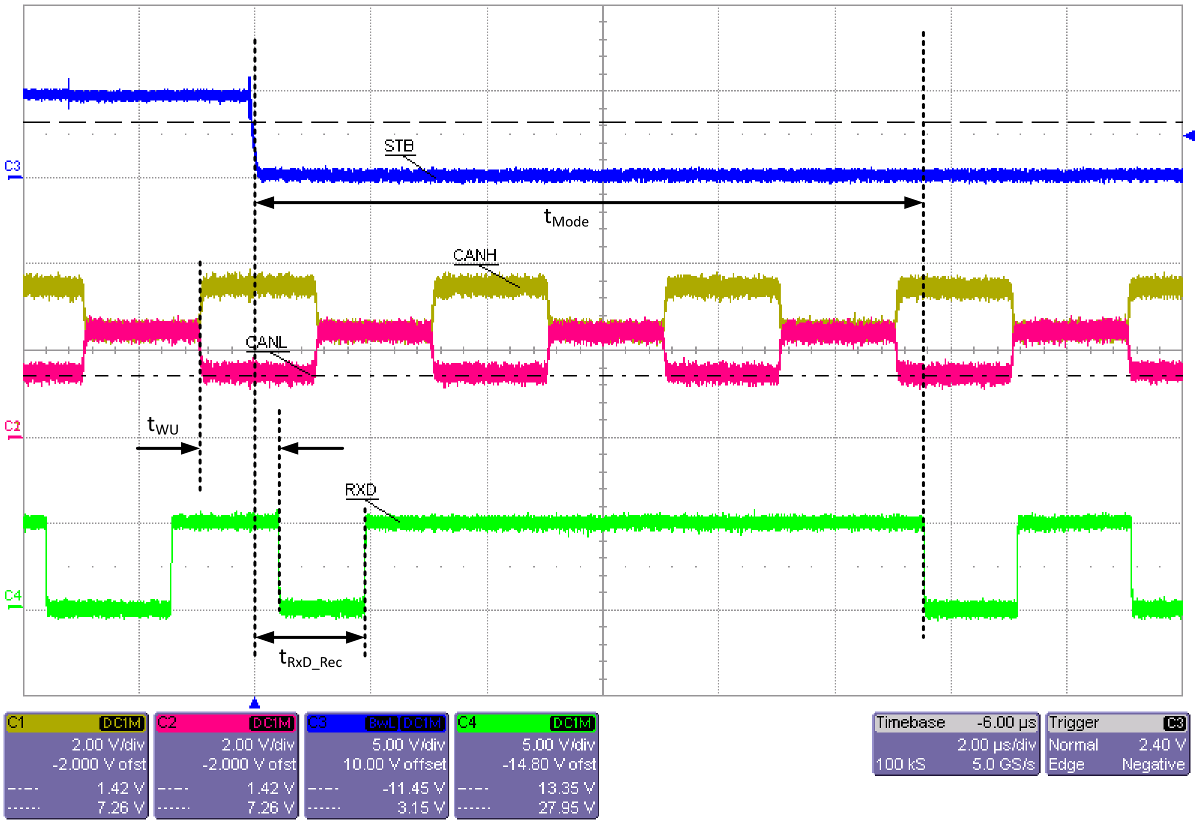


Figure 18 Communication on the CAN Bus: RxD Behavior during Mode Change (Stand-by Mode to Normal-Operating Mode) See Chapter 6.5 for t_{RxD_Rec}

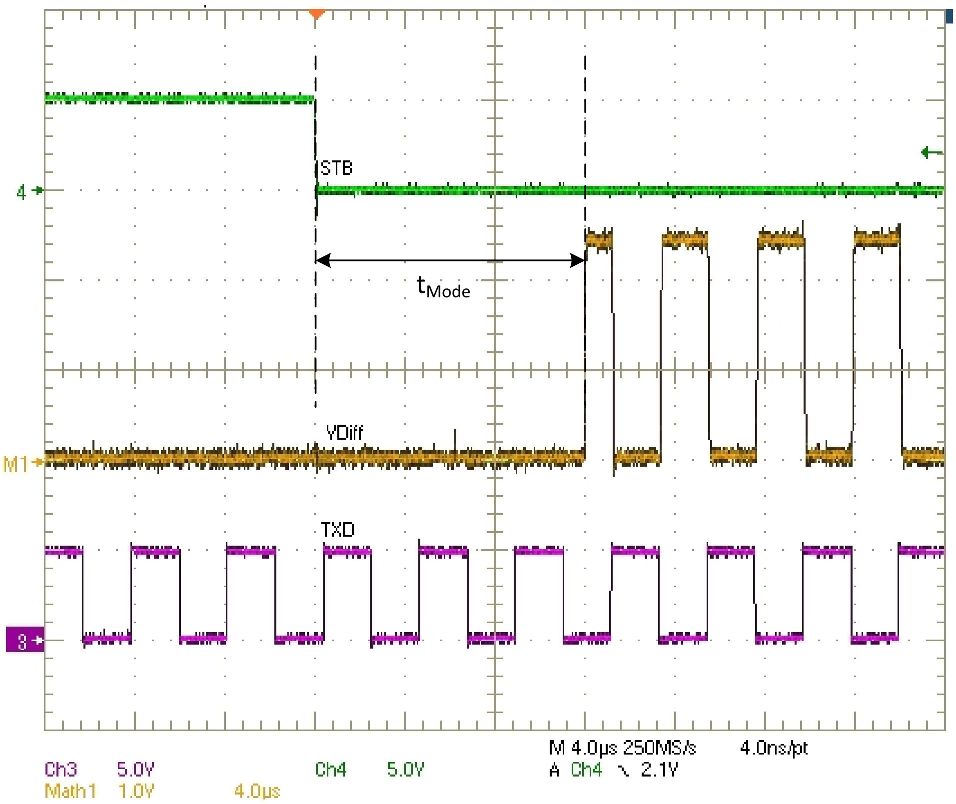


Figure 19 Mode Change Stand-by Mode to Normal-Operating Mode: Transmitter enabling

In Low-power Mode the bus biasing is connected to GND. In Normal-operating Mode the bus biasing is connected to $V_{CC}/2$. When changing the mode of operation from Low-power Mode to Normal-operating Mode the bus biasing is changed from GND to $V_{CC}/2$. **Figure 20** shows an example measurement in a networkehavior when the bus biasing is enabled.

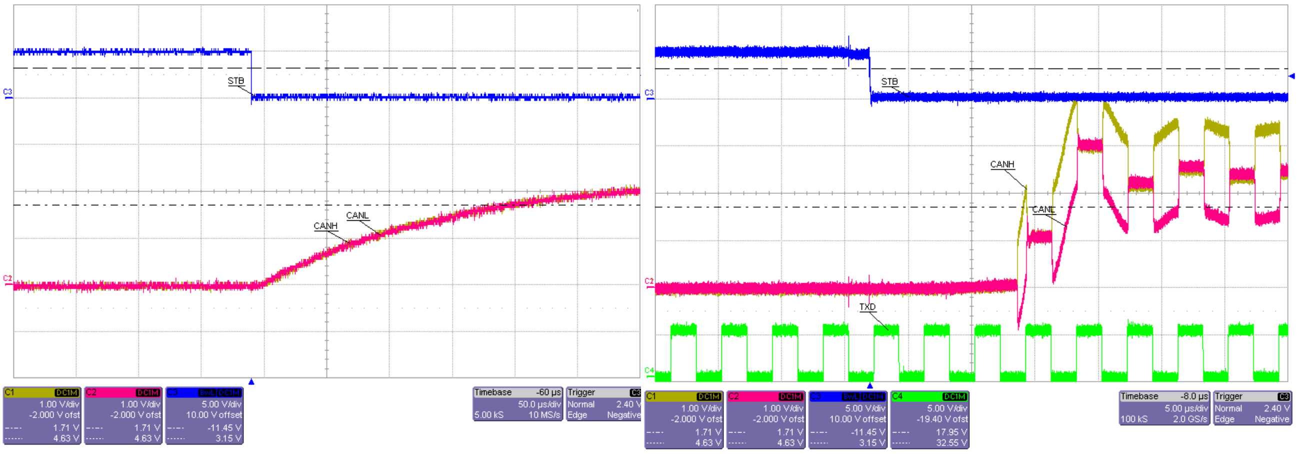


Figure 20 Mode change Low-power Mode to Normal-operating Mode: Bus Biasing enabled

6.3 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 TLE9251V changes from Normal-operating mode to Forced-receive-only mode. As soon as TLE9251V detects an undervoltage, it disables the transmitter output stage so that no faulty data is sent to the HS CAN bus.

During $V_{CC} < V_{CC(UV)}$ fault condition, the TLE9251V is set to Forced-receive-only mode the TLE9251V behaves as in Receive-only mode. The receiver is enabled and converts the signals from the bus to a serial data stream on the RxD output pin.
If V_{CC} recovers, then $V_{CC} > V_{CC\_UV}$ triggers a mode change back to Normal-operating mode.

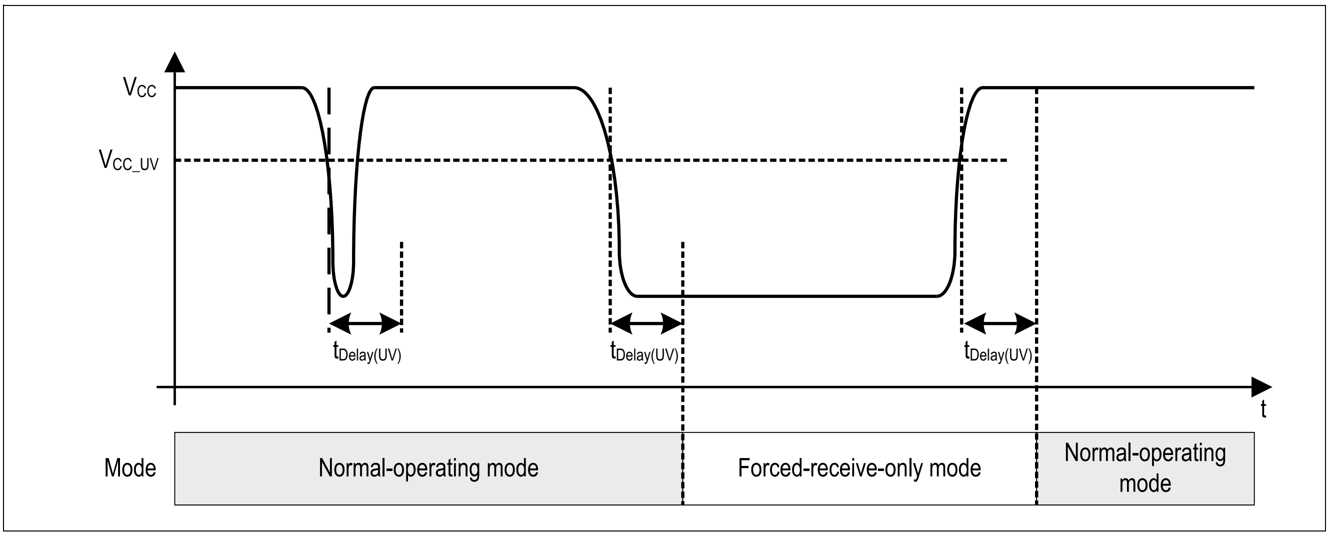


Figure 21 V_{CC} Undervoltage and Recovery

6.4 Wake-up Pattern (WUP) Detection

In order to reduce current consumption of permanently supplied applications (Clamp 30), ECUs can be set to a low power mode. Low-power mode reduces quiescent current. Usually the microcontroller is in stop mode and the transceiver is Stand-by mode. In Stand-by mode the transceiver can wake up the microcontroller in order to set the ECU back to normal operation.

The TLE9251V has a wake-up pattern (WUP) feature. This is called bus wake-up in ISO 11898-2 (Edition 2016). In Stand-by mode TLE9251V monitors activity on the CAN bus. If TLE9251V detects a wake-up pattern, it indicates the wake-up signal on the RxD output pin. In Stand-by mode the transmitter supply V_{CC} can be turned off. In Stand-by mode a wake-up event on the HS CAN is indicated on the RxD output pin. The transceiver remains in the current mode of operation.

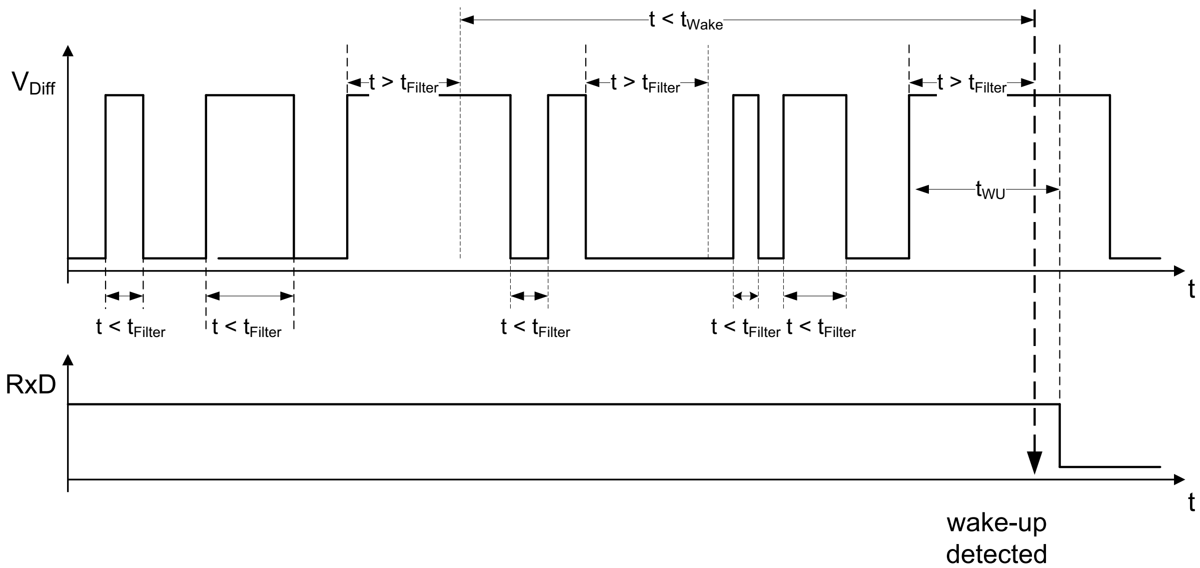


Figure 22 WUP Detection

Within maximum wake-up time t_{WAKE}, the wake-up pattern must contain a dominant signal with the pulse width t_{Filter}, followed by a recessive signal with the pulse width t_{Filter} and another dominant signal with the pulse width t_{Filter}. Wake up pattern detection is reset after t_{WAKE} expires. The wake-up pattern is valid also with additional dominant and recessive states shorter than t_{Filter}, which occur within the time period t_{WAKE} (see **Figure 22**). The RxD output pin remains "high" until a valid wake-up pattern is detected.

In order to ensure robust wake-up pattern detection within CAN FD networks the new ISO11898-2 (2016) has introduced two new parameters:

- t_{filter} < 1.8µs
- t_{WAKE} < 10ms

TLE9251V fulfills both parameter specifications according to ISO11898-2 (2016).

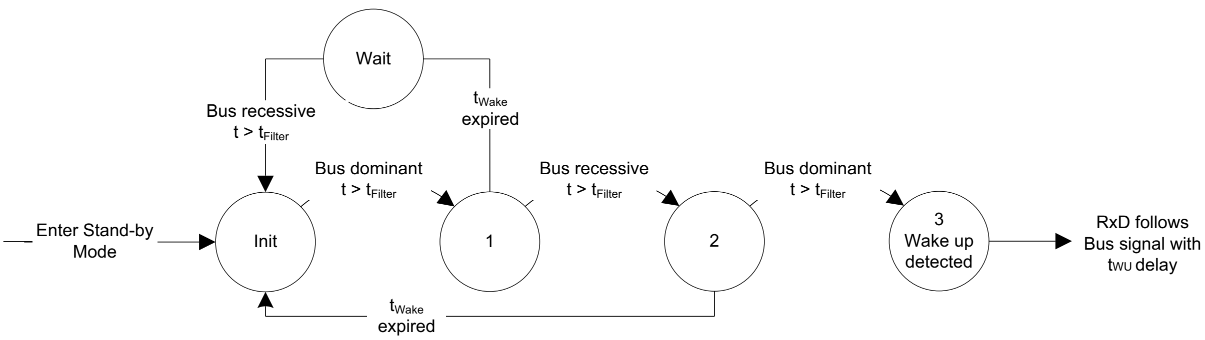


Figure 23 WUP Detection according to ISO 11898-2 (Edition 2016)

6.5 WUP Detection and Mode Change

Figure 24 shows WUP detection with a mode change while the bus is dominant and TxD input signal is set to "high". See **Figure 18** for example measurement

If a valid WUP has been detected, the signal at RxD output pin follows the HS CAN Bus signal with the delay of t_{WU}. During the mode transition from Stand-by mode to Normal-operating mode the RxD output pin is blocked and set to "high" with a delay of t_{RxD_Rec} < 5µs. After the transition time period t_{Mode} the RxD output pin is released and follows the dominant signal on the HS CAN Bus.

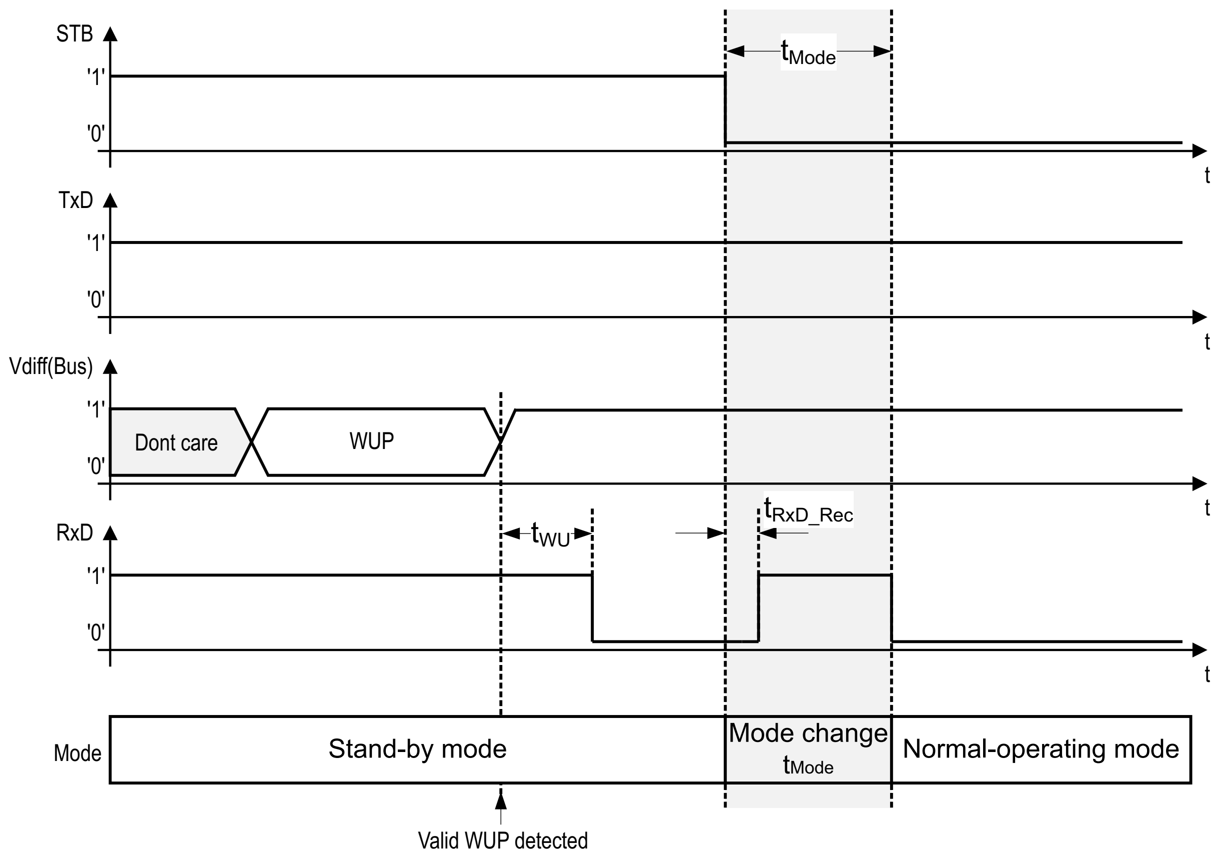


Figure 24 Mode Change Timing during Bus Dominant

6.6 Benefit of V_{IO}-supplied Wake Receiver

Infineon's HS CAN transceivers use the V_{IO} pin to supply the low-power-receiver. For transceivers with bus wake-up TLE9251V, only V_{IO} must be supplied in Stand-by mode. The application saves current with the ECU in Stand-by mode while waiting for a bus wake-up.

In Stand-by mode V_{CC} can be switched off, while the low power receiver can still wake up the microcontroller via a bus wake-up. Common CAN transceivers use V_{CC} to supply both the receiver and the logic, thus requiring two voltage regulators in operation for V_{CC} and V_{IO} for detecting bus wake-up. This increases current consumption in Stand-by mode. With Infineon's TLE9251V the user can switch off the V_{CC} voltage regulator, so no permanent current $I_{BAT,LDO}$ flows to the 5 V LDO. A permanently flowing current through the V_{CC}-LDO might be an issue for the ECU's efficiency.

In order to take advantage of the bus wake-up feature, the microcontroller must set the TLE9251V to Stand-by mode by setting the STB pin to "high" and needs to switch off the V_{CC} LDO by a Control Output, before the microcontroller itself changes to low-power mode.

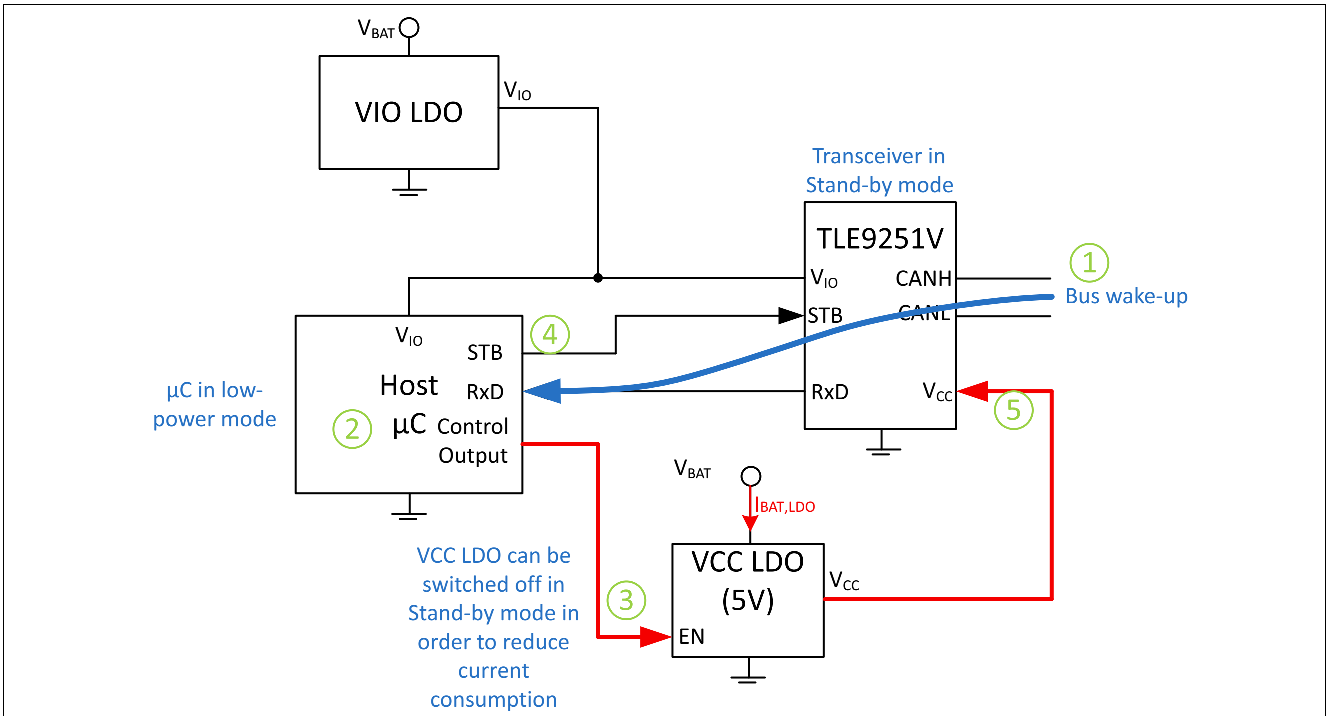


Figure 25 Advantage of V_{IO}-supplied Wake Receiver

Procedure for bus wake-up:

1) Bus-wake up is signaled by TLE9251V on the RxD output pin to the microcontroller

2) Microcontroller wakes up

3) Microcontroller switches on the V_{CC} LDO by the Control Output

4) Then the STB input pin of TLE9251V must be changes to "low" in order to trigger a mode change to "Normal-operating mode

5)After the mode change time t_{Mode} TLE9251V can send and receive data to the HS CAN Bus as soon as $V_{CC} > V_{CC\_UV}$

6.7 Pretended Networking Usage (Benefit of Forced-Receive-Only Mode)

Infineon's HS CAN transceivers use the V_{IO} pin to supply the internal logic of the transceiver. The transmitter of TLE9251V is supplied by V_{CC} (typ. = 5 V). This enables TLE9251V to support the Forced-receive-only mode, which is similar to the Receive-only mode. Even if $V_{CC} < V_{CC(UV)}$ due to a fault condition (undervoltage or short circuit of V_{CC} to GND) or if V_{CC} is completely switched off, then the receiver is enabled and provides data from the CAN bus to the RxD pin. This means the microcontroller can still receive all data sent to the CAN bus by other ECUs in CAN FD up to 5 Mbit/s.

The microcontroller can control the V_{CC} voltage regulator. In order to set the TLE9251V to Forced-receive-only mode the microcontroller switches off the V_{CC} voltage regulator. Typical use cases for Forced-receive-only Mode are:

- Pretended Networking:
  Most microcontrollers include power saving modes. Power saving modes set parts of the microcontroller to a low-power mode while other function blocks remain active. This mode is often also called Stop mode. The V_{CC} LDO is switched off and the TLE9251V is in Forced-receive-only mode. The CAN protocol handler of the microcontroller is enabled and monitors communication on the HS CAN bus. If the microcontroller detects a specific CAN message, then the microcontroller exits the low power mode and switches on the V_{CC} LDO. After switching on the V_{CC} LDO, TLE9251V enters Normal-operating mode and the ECU is fully functional and able to participate in the CAN communication. During vehicle operation, the aim is to reduce power consumption any time functions are not being used. Therefore Pretended Networking can be used to reduce current consumption of an ECU.
- Babbling Idiot protection:
  If a CAN controller gets out of control and transmits unintentionally messages to the bus, then this will block other communication on the HS CAN bus. In Forced-receive-only mode the transmitter of TLE9251V is disabled, the babbling idiot stops transmitting and the CAN bus is released, allowing other CAN controllers to communicate. This is important for high system reliability of an application.
- Additionally during voltage transient on V_{CC} supply, when $V_{CC} < V_{CC\_UV}$, the normal receiver remains fully functional. If there is communication on the HS CAN Bus, the receiving node is still capable to receive messages (Classical CAN and CAN FD) on the bus when $V_{CC} < V_{CC\_UV}$ and will not be disconnected from communication. As result during $V_{CC} < V_{CC\_UV}$ failure, less error messages will be sent out to the CAN bus, which enables more robust and reliable communication in the CAN bus network.

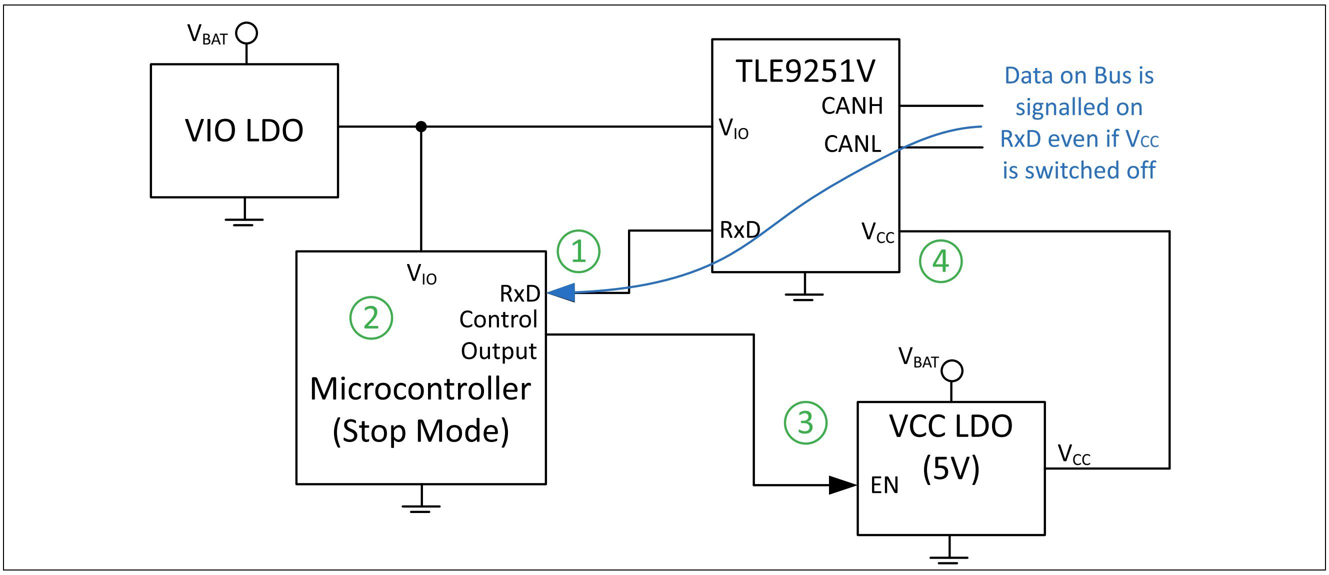


Figure 26 Pretended Networking using Forced-receive-only mode

Procedure for Pretended Networking:

1) TLE9251V is in Forced-receive-only mode. All messages on the bus are signalled on the RxD output.

2) Microcontroller is in Stop mode. The CAN protocol handler is enabled. Detecting a dedicated valid CAN frame, the microcontroller exits the Stop mode and ramps up to be fully functional.

3) Microcontroller switches on the V_{CC} LDO.

4) As soon as $V_{CC} > V_{CC\_UV}$, the TLE9251V enters Normal-operating mode and the ECU is able to participate in the CAN communication.

6.8 Transition from Stand-by Mode to Forced-Receive-Only Mode

From Normal-operating mode the TLE9251V enters Forced-receive-only on detecting V_{CC} undervoltage. However, in Stand-by mode V_{CC} undervoltage detection is disabled. With V_{CC} below the undervoltage threshold V_{CC_UV} in Stand- by mode, when STB is be switched from "high" to "low" the TLE9251V 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-receive-only mode. The overall transition time period from Stand-by mode to Forced-receive-only Mode is $t < t_{Mode}$. During the mode change from Power-save mode to Forced-receive-only 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-receive-only mode is completed, the TLE9251V releases the RxD output pin.

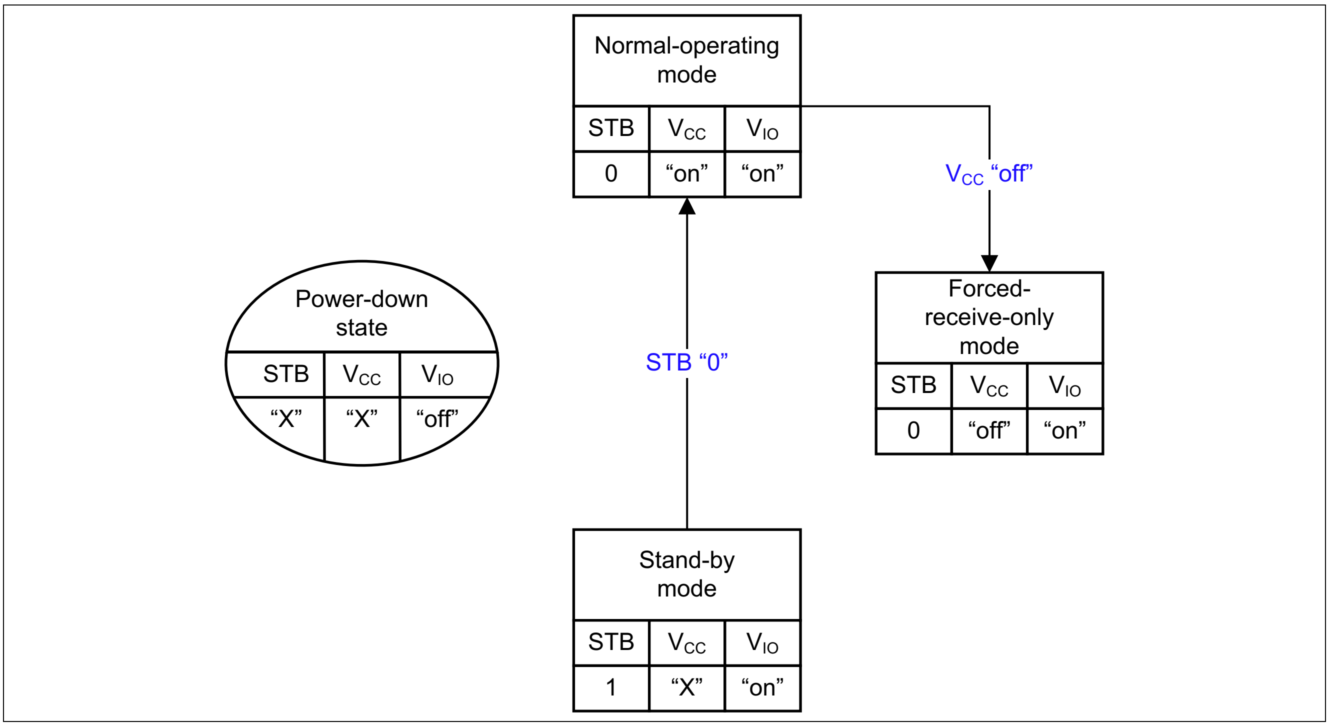


Figure 27 Stand-by Mode to Forced-Receive-Only Mode

7 Failure Management

This chapter describes typical bus communication failures.

7.1 TxD Dominant Time-out Detection

The TxD dominant time-out detection of TLE9251V protects the CAN bus from being permanently driven to dominant level. When detecting a TxD dominant time-out, the TLE9251V 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.

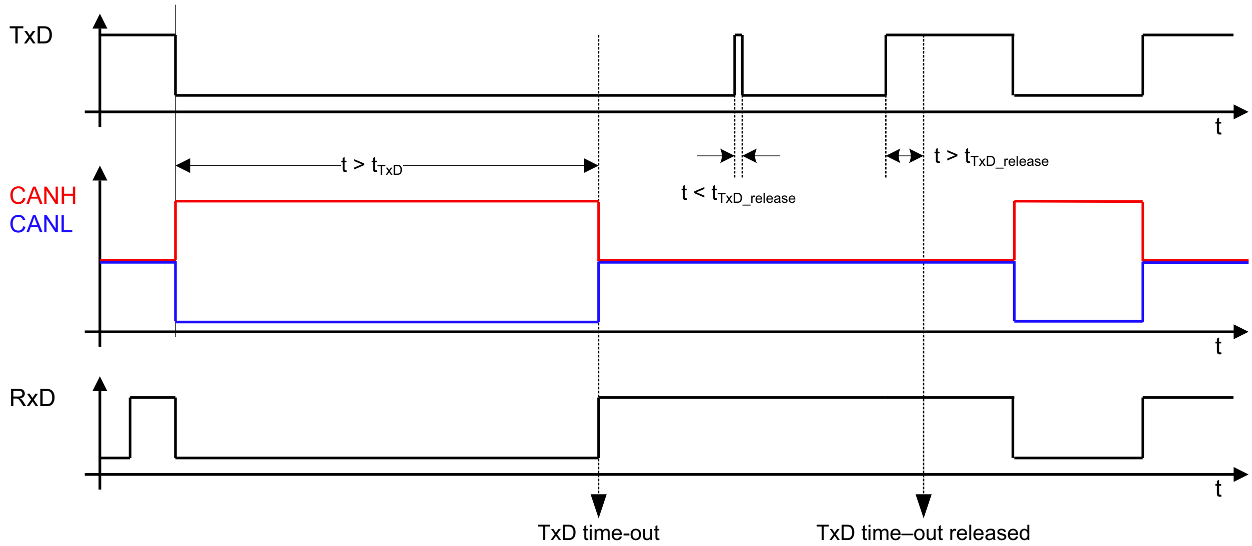


Figure 28 Resetting TxD Dominant Time-out Detection

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

7.2 Minimum Baud Rate and Maximum TxD Dominant Phase

Due to the TxD dominant time-out detection of the TLE9251V the maximum TxD dominant phase is limited by the minimum TxD dominant time-out time t_{TxD} = 1ms. 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 1 ms given in the datasheet and maximum possible 11 dominant bits, the minimum baud rate of the application must be higher than 11 kbit/s.

7.3 Short Circuit

Figure 29 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.

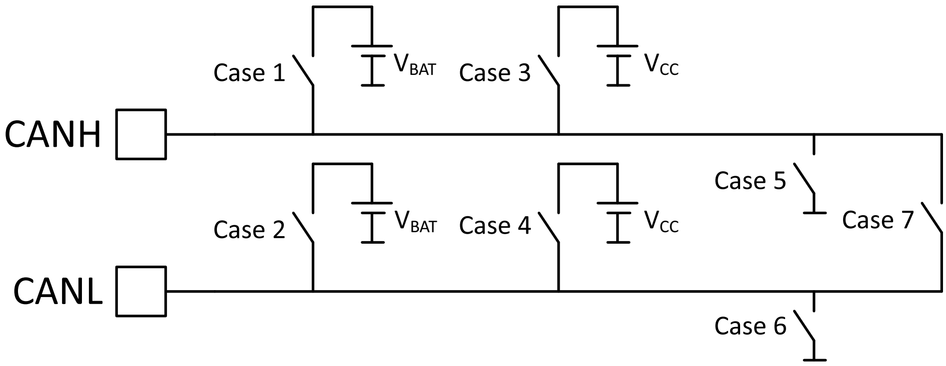


Figure 29 HS CAN Bus Short Circuit Types

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, 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 only increases in dominant state. The recessive current remains almost unchanged.

CANH shorted to GND

A maximum short circuit current of 115mA is specified. When transmitting a dominant state to the bus, V_{CC} is shorted to GND through the transmitter output stage. Power dissipation

U x I = 0.1 x 5V x 115mA = 0.0575W.

The average fault current with worst case parameters and assuming a realistic duty cycle of 10% is:
$I_{CC,Fault} = I_{CC,rec} \times 0.9 + I_{CANH,SC} \times 0.1 =$ 15.1 mA.

CANL shorted to V_{BAT}

If CANL is shorted to V_{BAT}, the device heats up. The datasheet specifies a maximum short circuit current of 115mA. 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 115mA = 0.1 x 18V x 115mA = 0.207W.

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 resistor and parallel internal resistors of the CAN nodes. If a short circuit of CANH to V_{BAT} occurs, then the power loss in the termination resistor must be taken into account. Figure 30 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 115mA) x 115mA = 0.7935W

P_{Loss_CANL} = 0.1 x (V_{BAT} - ($R_{Termination}$ x $I_{CANL,SC}$)) x $I_{CANL,SC}$)= 0.1 x (18V-6.9V) x 115mA = 11.1V x 115mA = 0.12765W

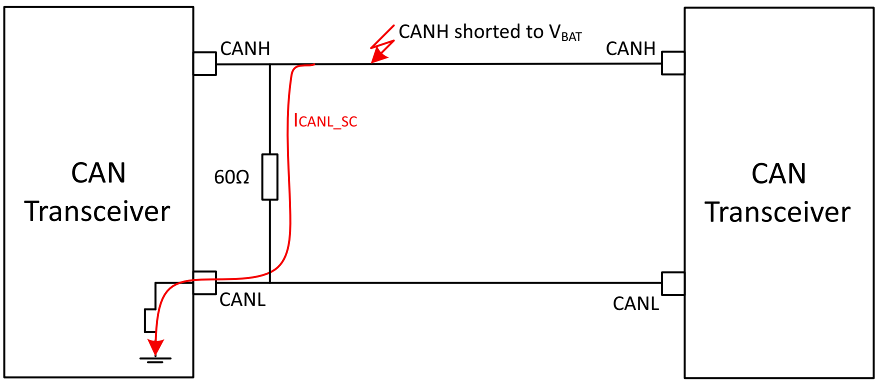


Figure 30 Current Flowing in Case of a Short Circuit CANH to V_{BAT}

7.4 TLE9251V Junction Temperature

In Normal-operating mode assuming sending five "dominant" bits followed by one "recessive" bit (83%) and 45% bus communication load for one node the power dissipation is as following:

P_{MAX} = 17% × 55% × (I_{CC_R} × $V_{CC,max}$) + 83% × 45% × ((1.4V/45 Ω x $V_{CC,max}$)-($V_{Diff\_EXT\_BL}$ x1.4V/45 Ω)) + (I_{IO} × $V_{IO,max}$) =
= 0.0935 × (4 mA × 5.5 V) + 0.310005 x ((31 mA × 5.5 V)-(1.4V × 31mA)) + (1.5 mA × 5.5 V) = 49.7 mW.

Junction temperature increases due to power dissipation.

However, typical conditions can be considered: Ambient temperature is below 150 °C, sending "recessive" and "dominant" bits 45% and 10% bus communication load for one node, supply voltages V_{CC} and V_{IO} have their typical values instead of maximum values. Power dissipation is much lower for typical conditions:

P_{AVG} = 55% × 90% × ($I_{CC\_R,Typ}$ × $V_{CC,typ}$) + 45% × 10% × ((1.7V/60 Ω x $V_{CC,typ}$)-(1.7 x 1.7V/60 Ω)) + ($I_{IO,Typ}$ × $V_{IO,AVG}$) =
= 0.495 × (2 mA × 5 V) + 0.045 x ((28 mA × 5 V)-(1.7V × 28mA)) + (1 mA × 3.3 V) = 10.1 mW.

Table 10 Increase of Junction Temperature ΔT_j

Package	R_{thja}	ΔT_j	**Conditions**
PG-DSO-8	120 K/W	10.3 K	P_{MAX} = 49.7 mW; T_{amb} = 150 °C; V_{CC} = $V_{CC,max}$; V_{IO} = $V_{IO,max}$
PG-TSON-8	65 K/W	5.63 K	
PG-DSO-8	120 K/W	1.6K	$P_{NM,AVG}$ = 10.1mW; T_{amb} = 80 °C; V_{CC} = $V_{CC,typ}$; V_{IO} = $V_{IO,typ}$
PG-TSON-8	65 K/W	0.87 K	
PG-DSO-8	120 K/W	6.9K	Short Circuit CANH to GND 10% duty cycle;
PG-TSON-8	65 K/W	3.74K	
PG-DSO-8	120 K/W	24.84K	Short Circuit CANL to V_{BAT} 10% duty cycle;
PG-TSON-8	65 K/W	13.45K	

If a short circuit occurs, then the TLE9251V heats up. The higher the duty cycle, the higher the power dissipation and thermal shutdown can occur due to high temperature. If the thermal shutdown is triggered, the transmitter disabled while the receiver is still active. The behavior is identical to Receive-only mode.

8 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, 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 shall be routed symmetrically close together with smooth edges with same length.
- GND connector should be placed as close as possible to the ECU track length of bus lines.
- 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. In case an external ESD protection circuit is required, it is recommended to place it as close as possible to the external connector (CAN bus and GND). Avoid long traces between external ESD protection circuit and CAN bus lines.
- For CAN FD application it is recommended to use a Common Mode Choke with 100µH impedance and Split termination with a capacitor of 4.7nF in order to achieve excellent EME performance.
- Avoid routing transceiver GND and other ECU component GND in series in order to avoid GND shift to other components. Therefore separate GND wiring of different components on ECU level is recommended.

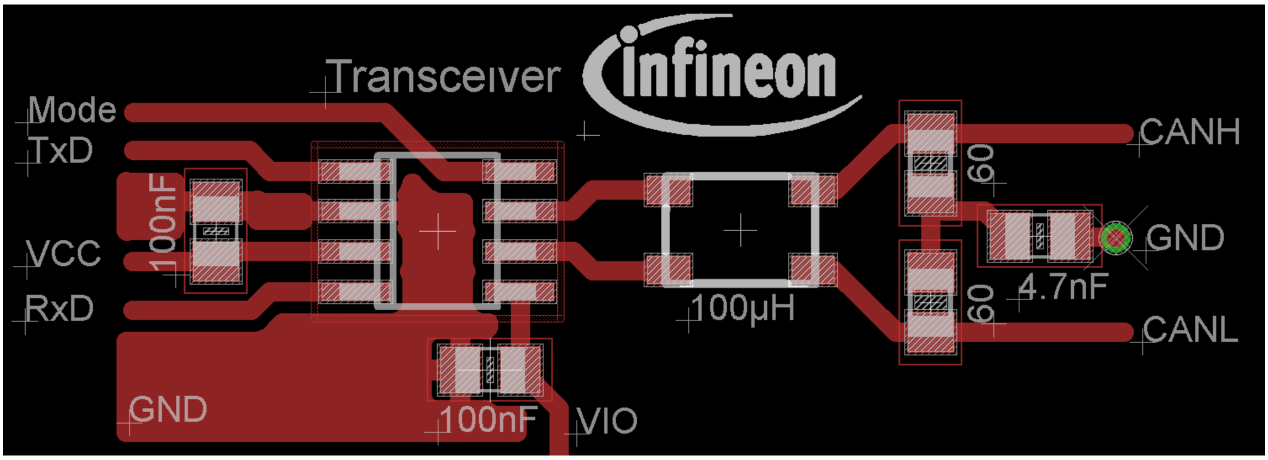
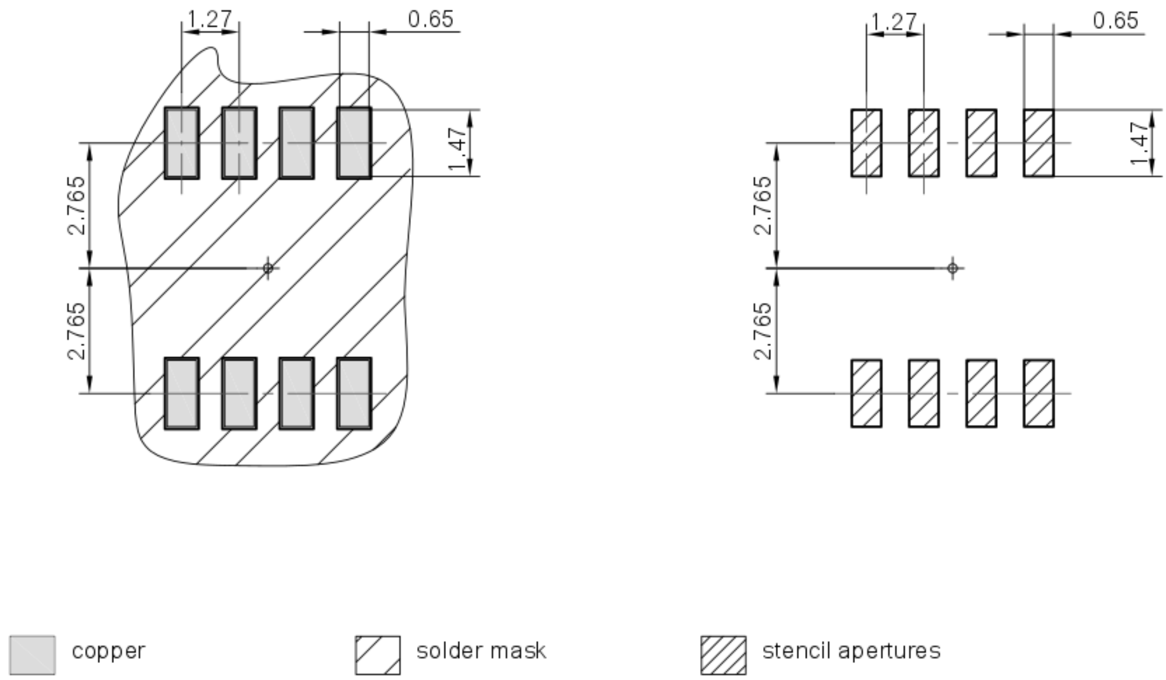


Figure 31 Example CAN transceiver PCB layout

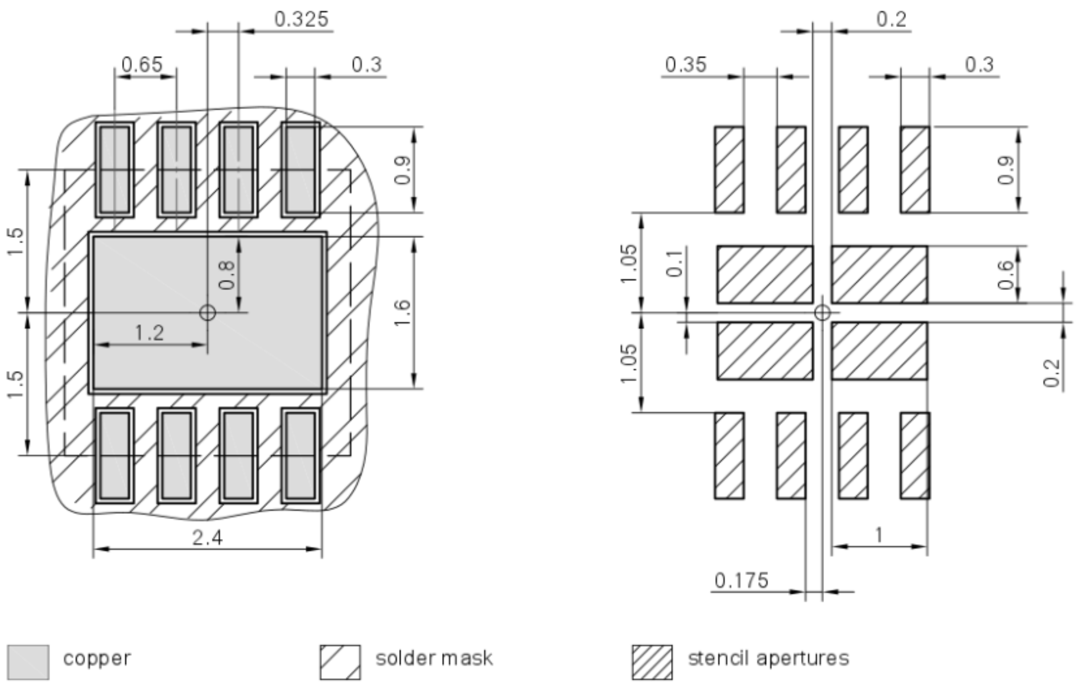
9 TLE9251V Footprint Dimensions for PCB Design

Figure 32 and **Figure 33** show the footprint dimensions for TLE9251V in DSO-8 and TSON-8 package. For further package information (e.g. packing) please visit **Infineon Packages Webpage**.



ALL DIMENSIONS ARE IN UNITS MM

Figure 32 TLE9251V Footprint Dimensions for DSO-8 Package



ALL DIMENSIONS ARE IN UNITS MM

Figure 33 TLE9251V Footprint Dimensions for TSON-8 Package

10 Pin FMEA

This chapter provides an Pin FMEA (Failure Mode and Effect Analysis) for typical failure situations. Typical failure scenarios for dedicated pins of TLE9251V 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 unconnected

The possible failures are classified according to possible failure effects (see **Table 11**)

Table 11 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 12 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.	C
TxD	Short Circuit to V_{CC} / V_{IO}	No damage to the transceiver. Possible damage of the microcontroller TxD pin in case $V_{IO} < V_{CC}$.	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

Table 12 Pin FMEA Overview

Pin	Potential Failure	Potential Effects of Failure	Class
V_{CC}	Short Circuit to V_{BAT}	Violation of absolute maximum ratings. Device gets damaged.	A
V_{CC}	open	No damage to the transceiver. No bus communication possible as the transmitter output stage is disabled. Low power mode or Forced-receive-only Mode can be entered. In Forced-receive-only Mode the receiver is active.	C
RxD	Short Circuit to V_{CC}	RxD remains "dominant". TLE9251V and µC might be destroyed. The CAN Controller will go in bus off. If $V_{IO} < V_{CC}$ the TLE9251V 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 may be damaged, due to high output current.	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 may be damaged, due to high output current.	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

Table 12 Pin FMEA Overview

Pin	Potential Failure	Potential Effects of Failure	Class
STB	Short Circuit to GND	No damage to the transceiver. The Device will enter Normal-operating Mode.	D
STB	Short Circuit to V_{BAT}	Violation of absolute maximum ratings. Device gets damaged.	A
STB	Short Circuit to V_{CC} / V_{IO}	Device will enter Stand-by Mode.	D
STB	open	No damage to the transceiver. Device will enter Stand-by Mode due to pull-up current source to V_{IO}.	D

Terms and Abbreviations

Table 13 Terms and Abbreviations

CMC	Common mode choke
EMC	Electromagnetic compatibility
EME	Electromagnetic emission
EMI	Electromagnetic interference
EOS	Electrical overstress
ESD	Electrostatic discharge
ESR	Equivalent Series Resistance
“high”	logical high
“low”	logical low
WUP	Wake-up pattern

11 Revision History

Revision	Date	Changes
1.0	2017-08-04	Application Note created

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