TLE8457xLE, TLE8457xSJ

LIN Transceiver with Integrated High Performance Voltage Regulator

About this document

Scope and purpose

This document provides application information for the transceiver TLE8457xLE/TLE8457xSJ from Infineon Technologies AG as Physical Medium Attachment within a LIN:

- Recommended setups for LIN master application and LIN slave application (see **Chapter 3**)
- Pin description (see **Chapter 4**)
- Mode control hints (see **Chapter 5**)
- Power-up sequences (see **Chapter 5.4**)
- Fail-safe features and behavior (see **Chapter 6**)
- Integrated Low Drop Output voltage regulator characteristics (see **Chapter 7**)
- Power consumption aspects (see **Chapter 8**)
- EMC aspects (see **Chapter 9**)
- ESD aspects (see **Chapter 10**)
- PCB recommendations (see **Chapter 11**)
- PIN FMEA (see **Chapter 12**)

This document refers to the data sheet of this transceiver **[1]**.

Intended audience

This document is intended for engineers who develop applications.

Table of Contents

1 Introduction to Local Interconnect Network (LIN)

The Local Interconnect Network (LIN) is a low speed class A serial bus system with a maximum baudrate of 20 kbit/s. Typical LIN bus system applications are:

- LIN slave satellite modules
- Window lifters
- Rain sensors
- Light sensors
- Sun roofs
- Wiper modules

The LIN bus system connects modules, actuators and sensors in a sub-bus system. A LIN network consists of a master LIN node and several slave LIN nodes (maximum 15 slave nodes). The master node controls the communication and access to the LIN bus.

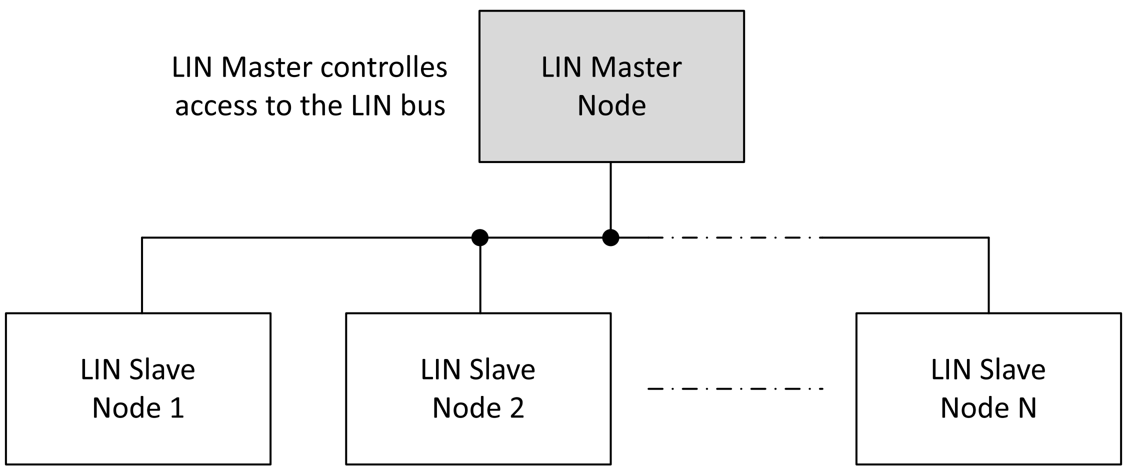


Figure 1 Master-slave LIN bus example

The LIN bus is a single wire, wired AND-bus with a 12 V battery related recessive level. The LIN Specification Package [2] defines the thresholds for the dominant level and the recessive level of the transmitting node and of the receiving node.

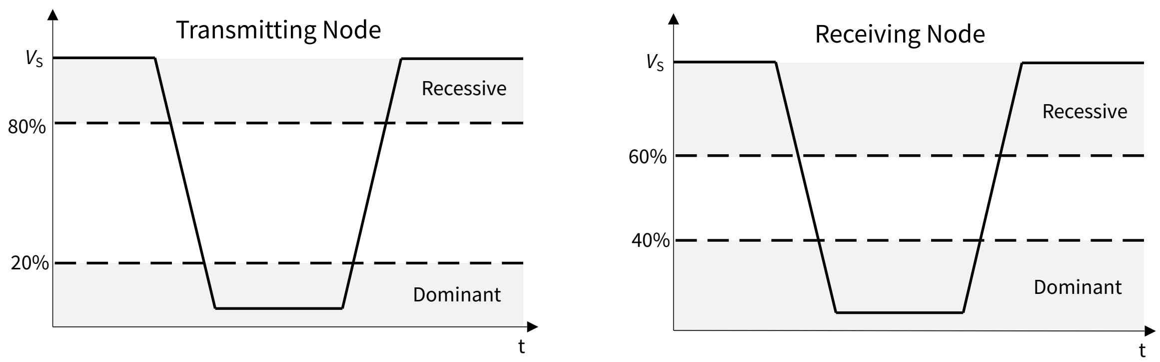


Figure 2 LIN voltage thresholds

2 General description

The transceiver TLE8457 represents the Physical Medium Attachment, interfacing the LIN master protocol controller and the LIN slave protocol controllers to the LIN transmission medium. The LIN transceiver converts the transmit data stream of the protocol controller at the TxD input to a bus signal with controlled slew rate to minimize Electromagnetic Emission (EME). The receiver of the TLE8457 detects the data stream on the LIN bus line and transmits the data stream to the protocol controller via the RxD pin.

The integrated high performance voltage regulator of the TLE8457 can drive a current up to 70 mA to external components, for example a microcontroller.

The TLE8457 provides low-power management modes with minimized current consumption (see **Chapter 8**):

- Sleep Mode
- Stand-by Mode

2.1 Features

The main features of the TLE8457 are:

- Single-wire LIN transceiver for transmission rates up to 20 kbit/s
- 5 V or 3.3 V Low Drop-Out Linear Voltage Regulator (LDO) with 70 mA current capability
- Stable LDO output voltage with ceramic output capacitor of 1 µF
- Very low current consumption in Sleep Mode: maximum 16 µA (typical 8 µA)
- Ultra low current consumption in Stand-by Mode: typical 20 µA
- Very low Electromagnetic Emission (EME) and high Electromagnetic Immunity (EMI)
- Excellent ESD performance according to HBM (+/-8 kV) and IEC (+/-8 kV)
- V_{CC} undervoltage detection with RESET output
- TxD dominant time-out function and state check after mode change to Normal Operation mode
- Initialization time-out fail-safe feature with automatic transition to Sleep mode (see **Chapter 6.1**)
- Overtemperature protection
- Supply undervoltage detection
- Available in standard PG-DSO-8 package and tiny PG-TSON-8 package

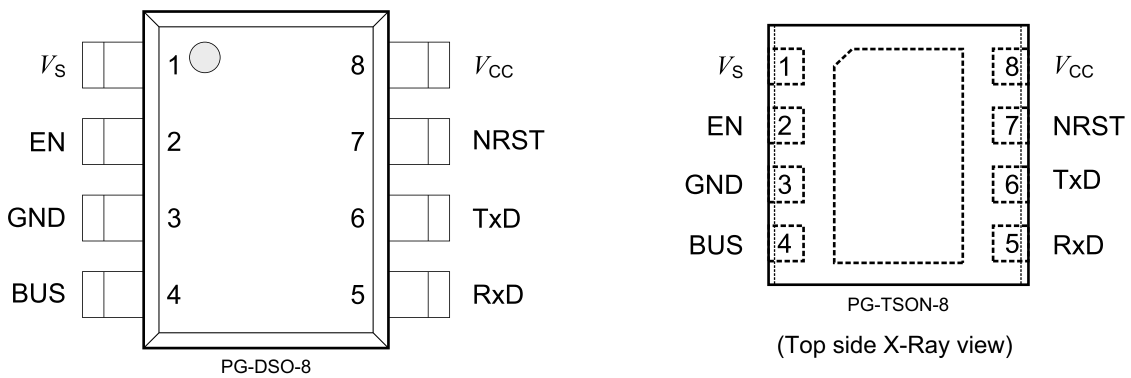


Figure 3 Pinout of TLE8457xLE/TLE8457xSJ

3 LIN applications

Types of LIN Applications:

- Slave node application
- Master node application

3.1 LIN slave node application

Figure 4 shows a slave application with the LIN transceiver TLE8457. The connection between the protocol controller (for example a microcontroller) and the LIN transceiver uses one of the following interfaces:

- UART/SCI
- standard I/O port pins

The TxD pin of the TLE8457 is the transmit data input. The RxD pin is the receive data output. A microcontroller port pin can control the sleep control input pin EN of the LIN transceiver. Because the TLE8457 provides an internal slave termination resistor, no extra LIN bus termination resistor is necessary in a slave application. The capacitor C_{SLAVE} in **Figure 4** is recommended in order to improve both EME performance and EMI performance of the LIN system, required according to LIN specification.

Due to the LIN Bus wake-up capability the slave node can be set to Sleep Mode to reduce current consumption to a minimum. In Sleep Mode the LDO is switched off. If a wake-up is detected, then the internal LDO is switched on again and the connected microcontroller ramps up and can set the TLE8457 to Normal-operating Mode.

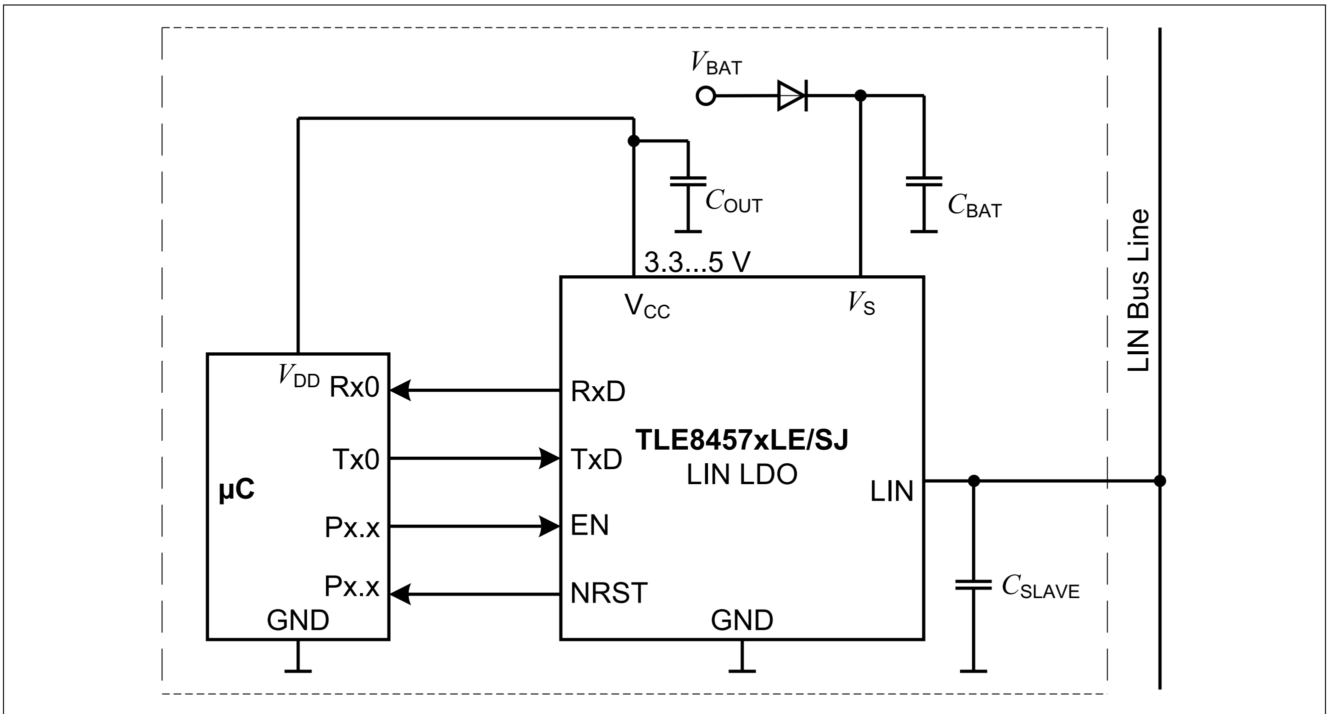


Figure 4 Slave node application example with TLE8457

3.2 LIN master node application

A master application requires of an extra master termination resistor R_{MASTER}. The capacitance load C_{MASTER} is recommended in order to improve EME as well as EMI. This master application uses a reverse current diode in series with the resistor R_{MASTER} connected between LIN and (see **Figure 5**).

R_{MASTER} = 1 kΩ according to the LIN 2.x specification and to ISO 17987. The OEM specifies the capacitance value of C_{MASTER}.

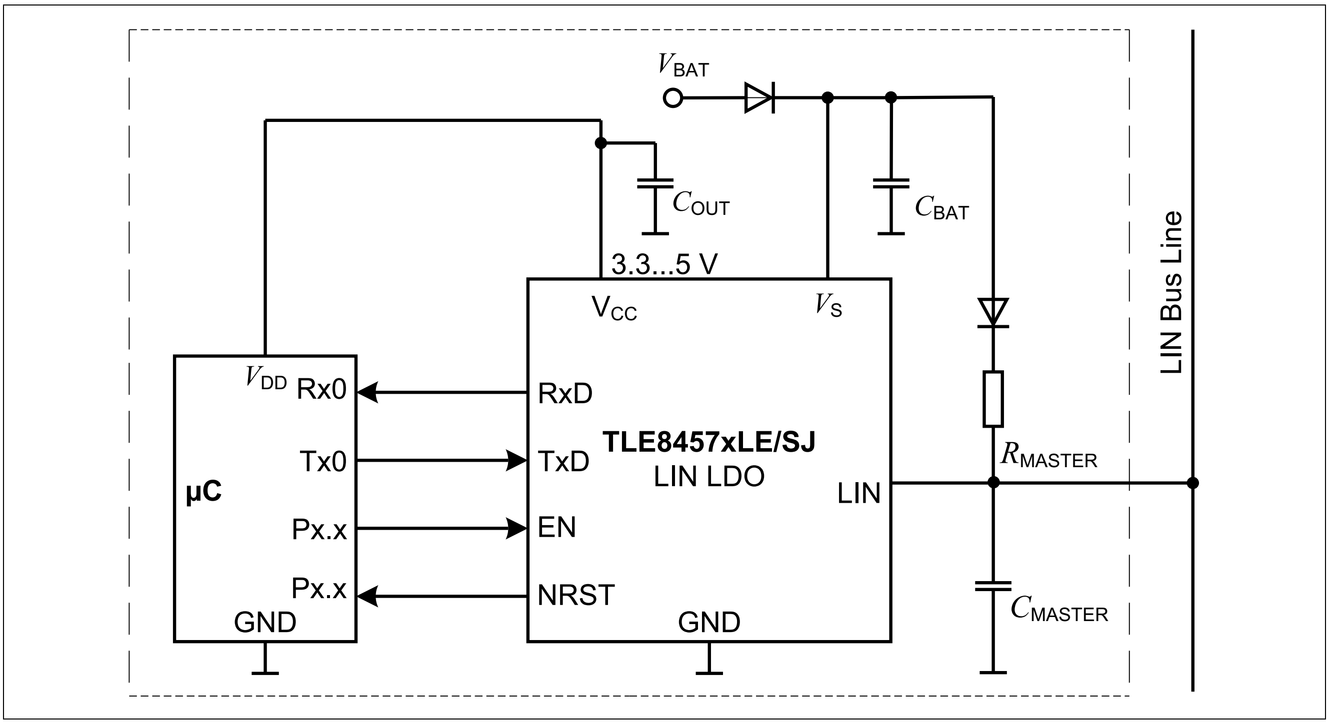


Figure 5 Master node application example with TLE8457

4 Pin description

TLE8457 is an 8-pin LIN transceiver according to the LIN Specification Package [2] with an integrated voltage regulator.

4.1 V_S pin

The V_S pin is the supply pin of TLE8457. It is recommended to place a reverse polarity protection diode between the battery voltage V_{BAT} and the V_S supply pin, in order to protect the device in case of reversed polarity of GND and V_S voltage. In order to dampen noise coupling through battery supply it is recommended to place external capacitors close to the V_S pin. The external capacitors should be dimensioned both for high and low frequency transients.

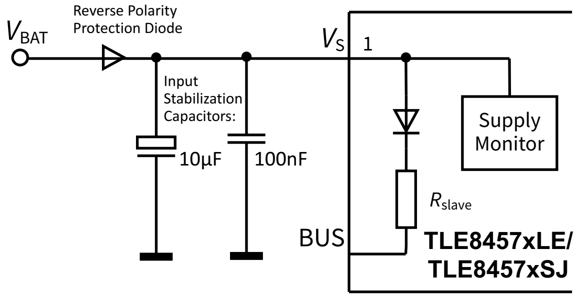


Figure 6 Typical V_S supply voltage output application

4.2 GND pin

The GND pin must be connected as close as possible directly to module ground in order to reduce ground shift. GND level must be identical for transceiver, microcontroller and LIN bus system.

4.3 EN pin

The EN input pin sets the mode of TLE8457. The EN input is usually connected to output ports of a microcontroller. The internal pull-down resistor R_{EN} of the EN input pin provides a defined input level in case of open circuit failure. If the EN pin is unconnected, due to the internal pull-down resistor the EN input signal is set to “low”. If the TLE8457 is supplied by V_S, the device will go to Init Mode and after expiration of the initialization watchdog time-out enters Sleep Mode (see **Chapter 5.3.2**). In Sleep Mode the power dissipation is reduced to a minimum. The range of the EN input threshold supports devices supplied at 5 V as well as devices supplied at 3.3 V. **Figure 7** shows a typical EN pin application.

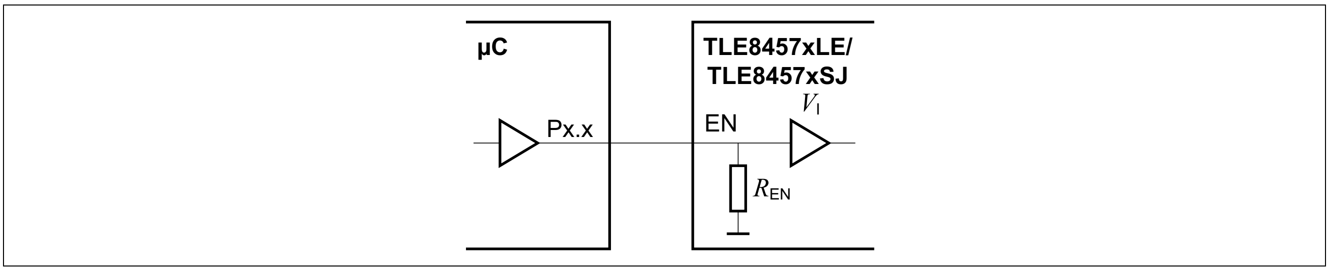


Figure 7 Typical EN pin application

4.4 NRST pin

The NRST output pin is usually be connected to the RESET input pin of the microcontroller. The NRST output pin is used to release the microcontroller during the start-up phase. The NRST pin indicates, whether the internal voltage regulator is operating:

- If V_{CC} drops below the undervoltage threshold $V_{CC} < V_{CC,UV}$, then the NRST pin is set to "low".
- If $V_{CC} > V_{CC,UV}$ for $t > t_{RST}$, then the NRTS pin is set to "high".

Because of the internal pull-up resistor no external pull-up resistor is needed.

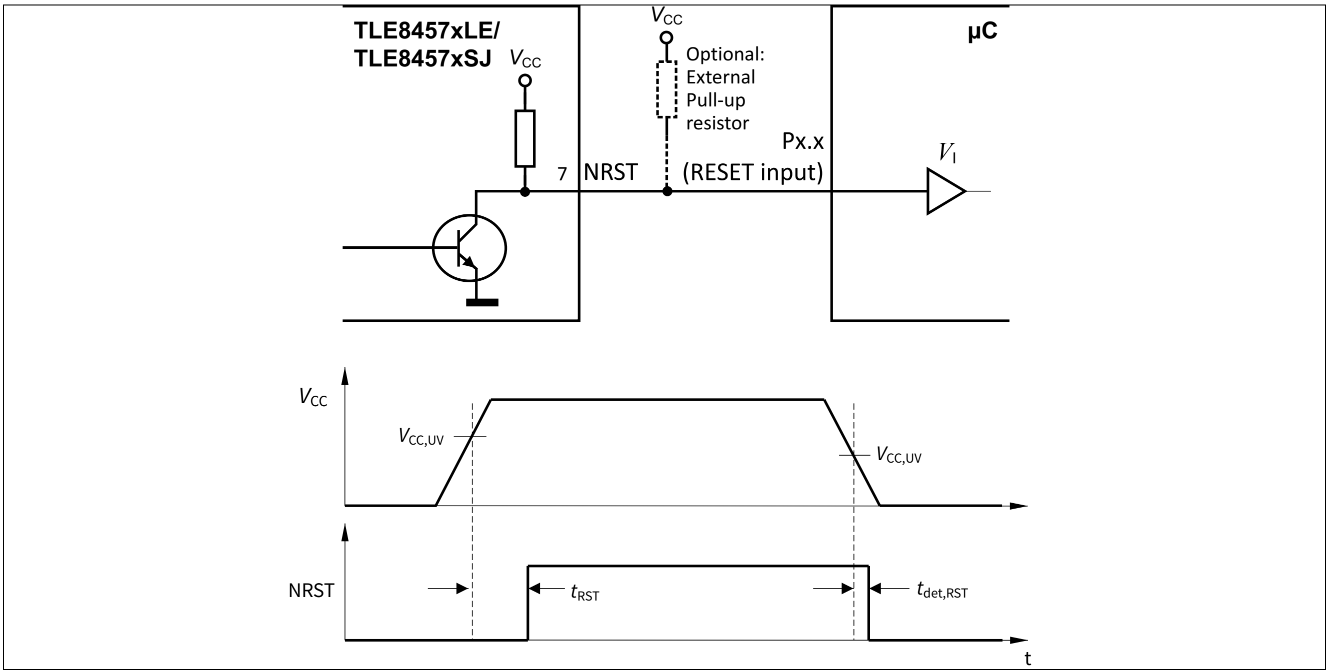


Figure 8 Typical NRST pin application and NRST switching behavior (See Figure 23 for measurement)

4.5 TxD pin

The TxD input pin receives the data stream from the microcontroller. In Normal-operating mode the transceiver transmits the data stream, which the microcontroller sends to the TxD pin, to the LIN bus. In any other mode the TxD input pin is blocked.

In Normal Operation Mode, in Init Mode and in Stand-by Mode the TxD pin provides an internal weak pull-up current source I_{TxD} to ensure a defined input level in case of open circuit failure. In case of permanent dominant TxD input level, the TxD dominant time-out function disables the transmitter to prevent the LIN bus from being clamped to a dominant level. If the TxD input pin is not connected, for example due to a PCB crack, then the internal pull-up resistor on TxD to V_{CC} forces the LIN output stage to a recessive signal. Because of the recessive signal the communication on the LIN bus is undisturbed.

4.6 RxD pin

RxD is an output pin. In Normal-operating mode the RxD output pin displays the data stream that is received from the LIN bus. Because of the push pull output stage of RxD to V_{CC} and GND no external pull-up resistor is needed. In Sleep Mode the RxD output pin is floating. The voltage supply input of the microcontroller should be connected to the V_{CC} output pin of the TLE8457 in order to adjust the voltage level of RxD and of the microcontroller ports to the microcontroller. **Figure 9** shows a typical RxD application.

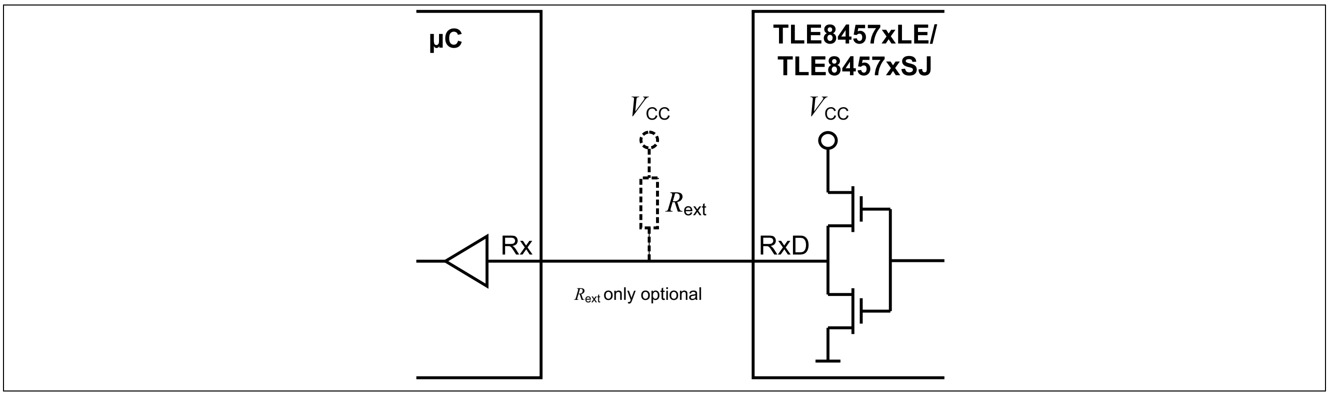


Figure 9 Typical RxD pin application

4.7 BUS pin

The BUS pin transmits and receives data on the LIN bus line. Internally a low side switch with controlled wave shaping transmits data, and the receiver receives data. The voltage threshold of the receiver V_{th} is battery related and has a hysteresis of V_{HYS}. The receiver thresholds, range and hysteresis fulfill the LIN 2.2A specification.

The BUS pin has a slave termination resistor R_{SLAVE}. The slave termination resistor as well as the low side switch use a reverse current diode. Thus no external components are required. However, placing capacitive load C_{SLAVE} at the LIN bus can improve EME and EMI (see **Figure 4**).

The BUS pin can withstand static voltage in the range of -27 V < V_{Bus} < 40 V for safe application usage. The BUS pin has a high ESD robustness and withstands voltage transients of +/- 8 kV according to IEC61000-4-2.

4.8 V_{CC} pin

The V_{CC} pin is the voltage regulator output pin. This pin can supply external components, for example a microcontroller. The integrated high performance voltage regulator is capable to drive a current up to 70 mA. An external stabilization capacitor of only 1 µF is required for a stable and robust supply output voltage. Therefore system cost saving on ECU level can be achieved. ceramic capacitors are recommended due to their low ESR. The TLE8457 has an internal pull-down resistor of typically 50 kΩ. The pull-down resistor discharges the output capacitor, when the device enters Sleep Mode and the internal voltage regulator is switched off. TLE8457 variants provide different supply output voltage:

- TLE8457ASJ/TLE8457ALE: 5 V supply output voltage
- TLE8457BSJ/TLE8457BLE: 3.3 V supply output voltage

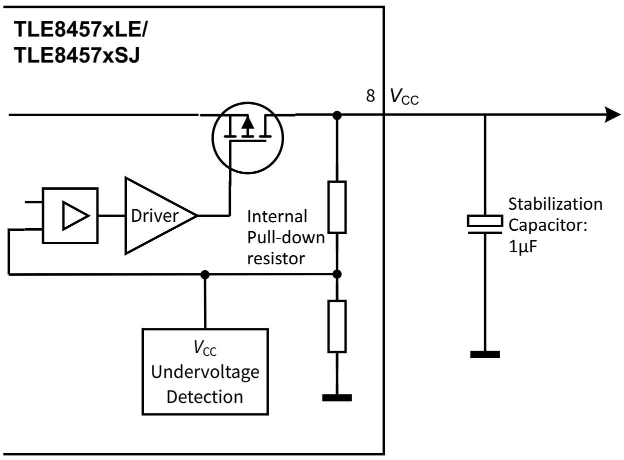


Figure 10 Typical V_{CC} supply voltage output application

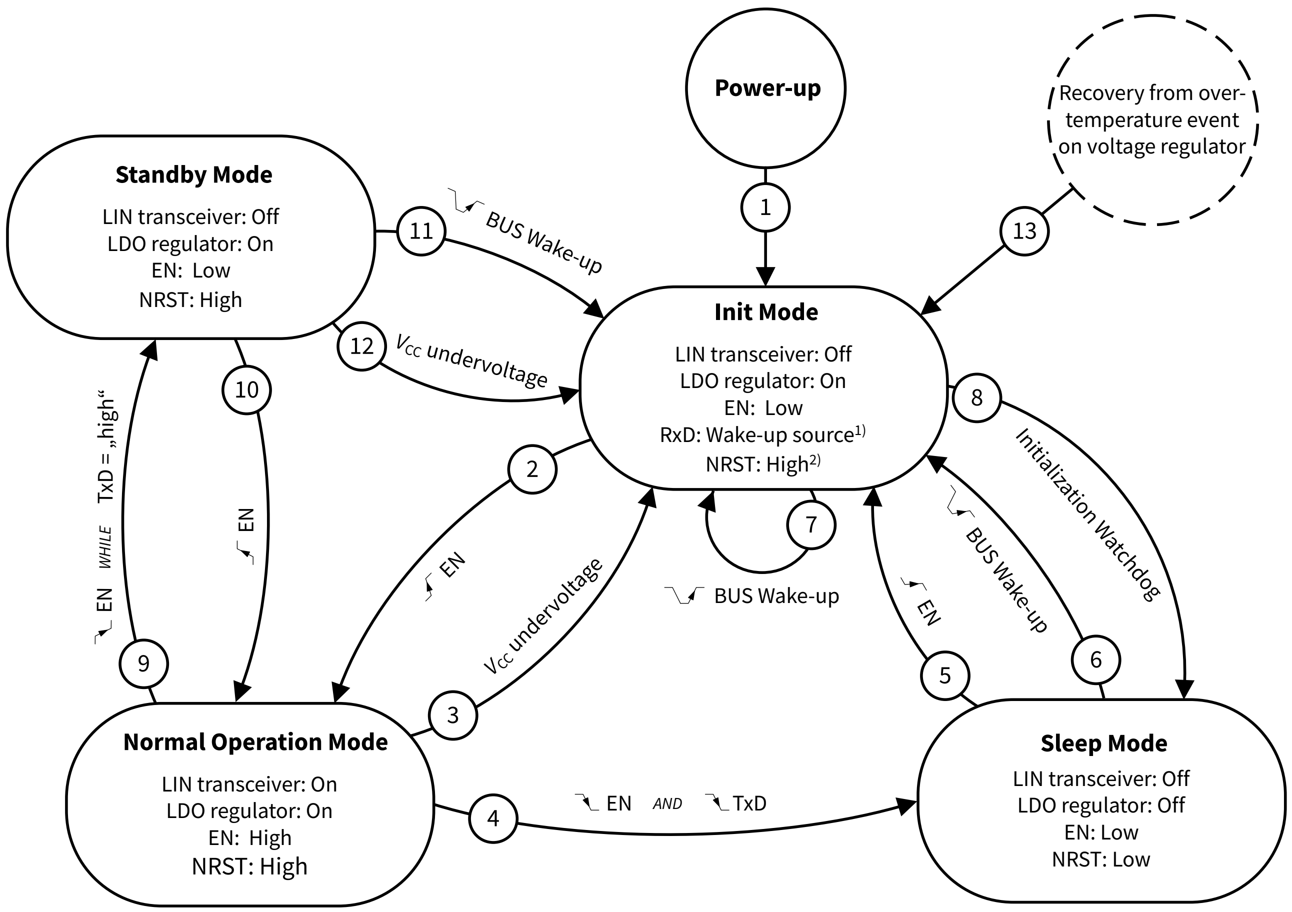
5 Transceiver control

This chapter explains the features available in different modes of operation and the mode change behavior of TLE8457.

5.1 Modes of operation

The following factors control the modes of operation:

- EN pin
- TxD pin
- state of V_{CC}
- bus Wake-up



1) **Wake-up Source**:
RxD: logical „high“ after Power-up or Reset
RxD: logical „low“ after BUS Wake-up detection

2) **Reset:**
NRST will stay „low“ during LDO failures and for the Reset time t_{RST}

Figure 11 State diagram

Table 1 Operating mode control

Mode	Control		Functionality			Comments
	EN	TxD	V_{CC}	NRST	RxD	
Sleep mode	Low	Low	Off	Low	Floating	–
Init mode	Low	High[1)]	On	High[2)]	Low High	RxD “low” after a bus wake-up RxD “high“ after power-up or reset
Stand-by mode	Low	High[1)]	On	High	High	–
Normal operation mode	High	Low High	On	High	Low High	RxD reflects the signal on the bus TxD driven by the microcontroller

1) The TxD input has an internal pull-up current source to V_{CC}. If TxD is left open, it is “high” by default.

2) NRST is “low” during V_{CC} undervoltage and while issuing a reset pulse to the microcontroller.

5.1.1 Normal Operation Mode

In Normal Operation Mode the TLE8457 transmits and receives data via the LIN bus line. The receiver converts the bus data stream to a digital bit stream and outputs it to the to the microcontroller via the RxD pin. A “high” level on the RxD pin represents a recessive level on the LIN bus line. A low level on the RxD pin represents a dominant level on the LIN bus line. The transmitter of the TLE8457 converts the data stream of the microcontroller at TxD input to a LIN bus signal with a constant slew rate to minimize EME independently of battery voltage. A low level on the TxD input pin results in a dominant LIN bus level, while a high level on the TxD input results in a recessive LIN bus level.

The internal slave termination resistor R_{BUS} pulls the LIN bus pin high.

The internal voltage regulator operates and can supply external components via V_{CC} supply pin.

5.1.2 Stand-by Mode

Stand-by Mode is a low-power mode, which is entered only from Normal Operation Mode by setting the EN pin to “low” while TxD is “high”. In Stand-by Mode the internal voltage regulator operates. If no wake-up event is detected, then the RxD pin is set to “high”. If a remote wake-up via LIN bus is detected, then the RxD output pin is set to “low”. This behavior of RxD can be used as wake-up interrupt request for a microcontroller.

5.1.3 Init Mode

After a power-up event the TLE8457xLE, TLE8457xSJ enters Init mode by default. In this mode the LIN transceiver is disabled, but the voltage regulator operates. After the linear voltage regulator reaches its nominal output voltage V_{CC} and if the NRST output is set “high”, the microcontroller can change the mode to Normal Operation mode. If the Initialization Watchdog timer elapses before a “high” signal is detected on the EN input, then the TLE8457xLE, TLE8457xSJ autonomously transitions to Sleep mode.

In addition to the EN input pin the following conditions can trigger a transition to Init mode:

- bus wake-up event on the BUS pin
- power-up event on the supply V_S
- power-on reset caused by the supply V_S
- voltage regulator failure event due to V_S undervoltage
- recovery from an overtemperature event on the voltage regulator

5.1.4 Sleep Mode

Sleep Mode of the TLE8457 provides the lowest power consumption achievable within LIN ECUs due to:

- very low current consumption of the transceiver
- disabled internal voltage regulator

Although power consumption is extremely low, remote wake-up via LIN is recognized and will result in a mode change towards Init Mode.

The TLE8457 is protected against unwanted wake-up events caused by automotive transients or EMI. For this purpose the transceiver provides filters and/or timers at the input of the receiver (BUS). Valid wake-up events must exceed a minimum time period ($t_{WK,bus}$, t_{Mode}).

Sleep mode is entered from Normal Operation Mode by setting the EN pin to “low” and setting the TxD pin to “low” for at least t_{Mode}. If LIN is clamped to ground, for example due to a short-circuit to GND, then entering Sleep Mode is still possible.

5.2 Mode change behavior

This chapter describes in detail the behavior of the TLE8457 during mode changes via:

- host command
- wake-up event
- power-up sequence

5.2.1 LIN bus Wake-up event

If the TLE8457 is in Sleep Mode or in Stand-by Mode, then a wake-up event triggers a mode change to Init Mode. In Init Mode the RxD output pin is set to “low” in order to indicate a wake-up event to the microcontroller.

In Stand-by Mode the RxD pin is set to “high”. A wake-up event is detected with a dominant signal on the LIN bus for $t > t_{WK,bus}$. RxD indicates the wake-up event with a falling edge, when the LIN bus signal changes to recessive again.

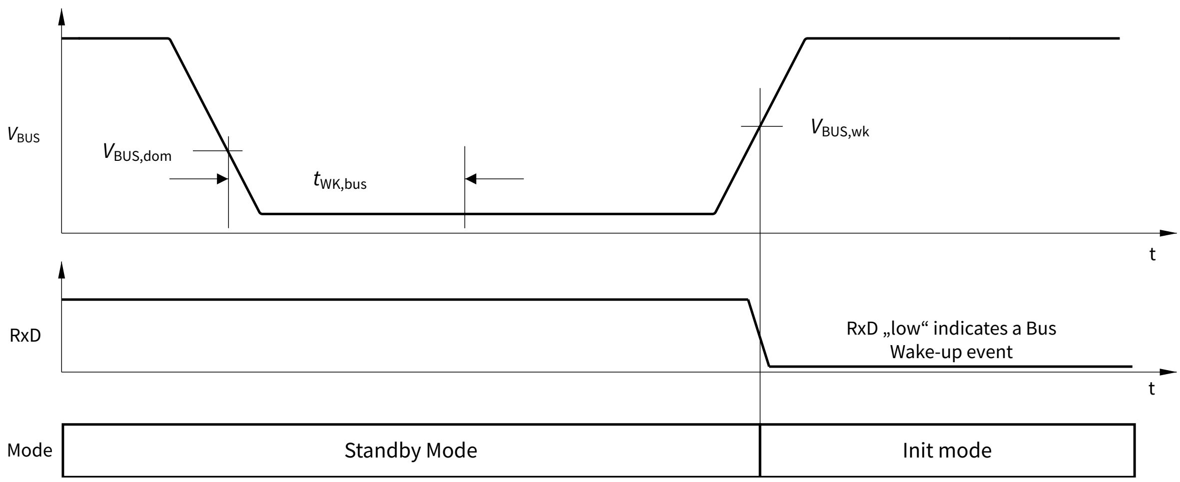


Figure 12 Wake-up via LIN bus in Stand-by Mode

A wake-up is detected with a dominant signal on the LIN Bus for $t > t_{WK,bus}$. A mode change is performed when the LIN bus signal changes to recessive again. The V_{CC} supply output ramps up, whereas RxD remains “low”. After $V_{CC} > V_{CC,UV,ON}$ for $t > t_{RST}$ the NRST pin changes to “high” to indicate stable V_{CC} supply voltage and to release the RESET input of the microcontroller.

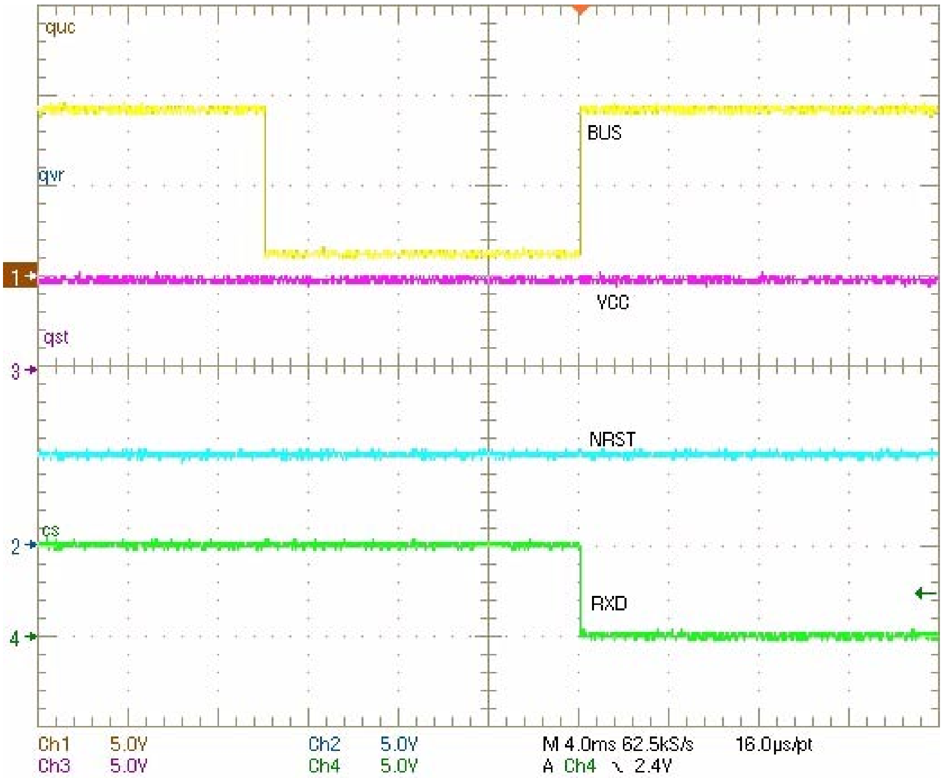


Figure 13 Measurement: Wake-up via LIN bus in Stand-by Mode

Because the RxD pin is floating in Sleep Mode, optionally an external pull-up resistor to V_{CC} of the TLE8457 can be placed to ensure a defined voltage level, when the V_{CC} output is switched off and pulled down to GND via the internal pull-down resistor.

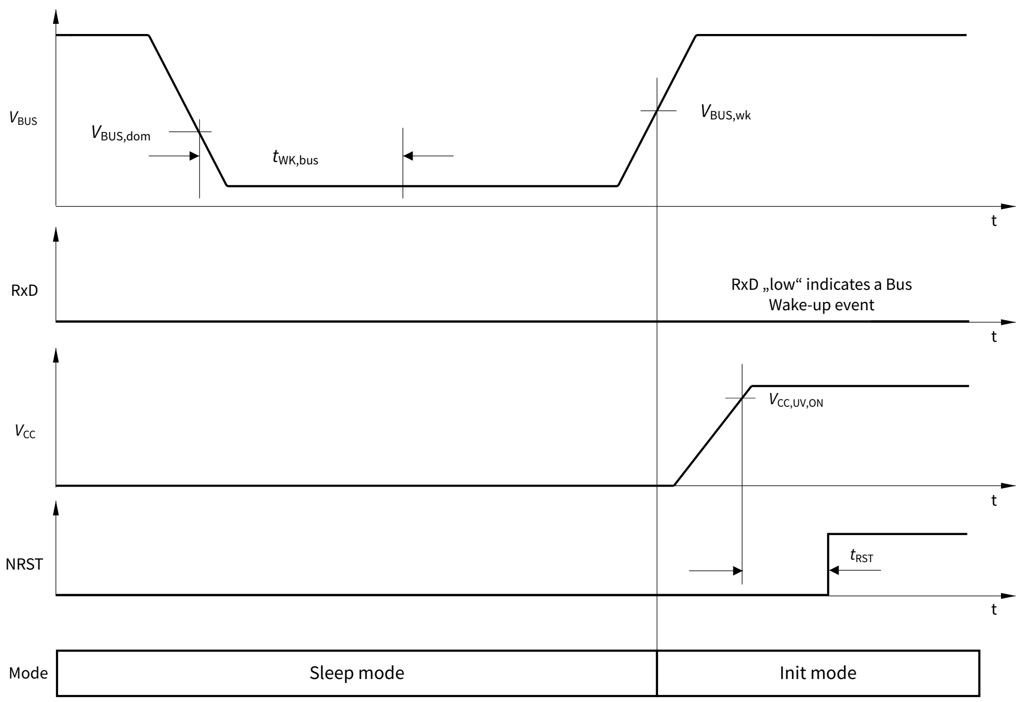


Figure 14 Wake-up via LIN bus in Sleep Mode

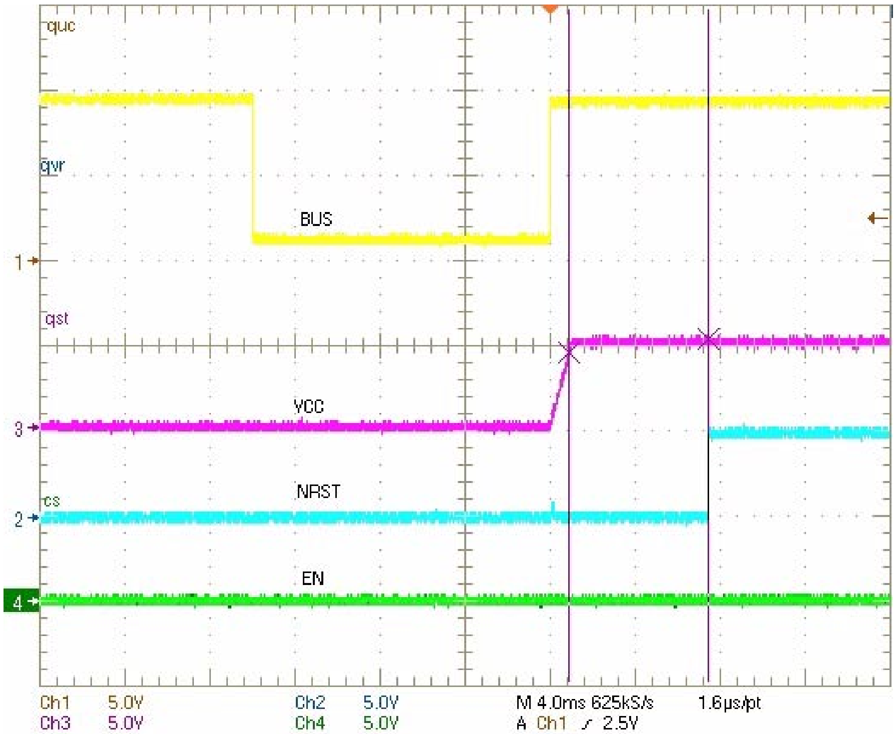


Figure 15 Measurement: Wake-up via LIN bus in Sleep Mode

5.2.2 Mode Change by EN pin

In Normal Operation Mode a falling edge on the EN input pin triggers a mode change either to Stand-by Mode or to Sleep Mode, depending on the input state on the TxD input pin (see **Figure 16**).

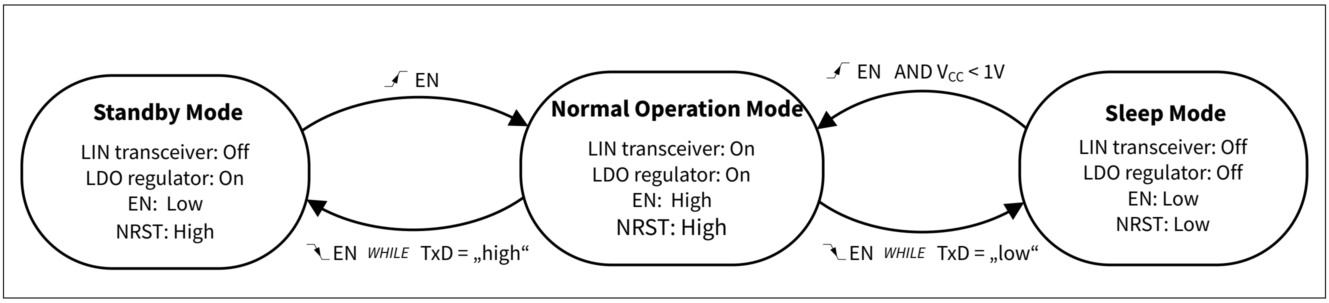


Figure 16 Transition from Normal Operation Mode to Sleep Mode or to Stand-by Mode

If the EN input is set to “low” while TxD input is “low” in Normal Operation Mode, then the TLE8457 enters Sleep Mode (see **Figure 17**). If EN pin is set to “low” while TxD input pin is “high” in Normal Operation Mode, then the TLE8457 enters Stand-by Mode (see **Figure 18**).

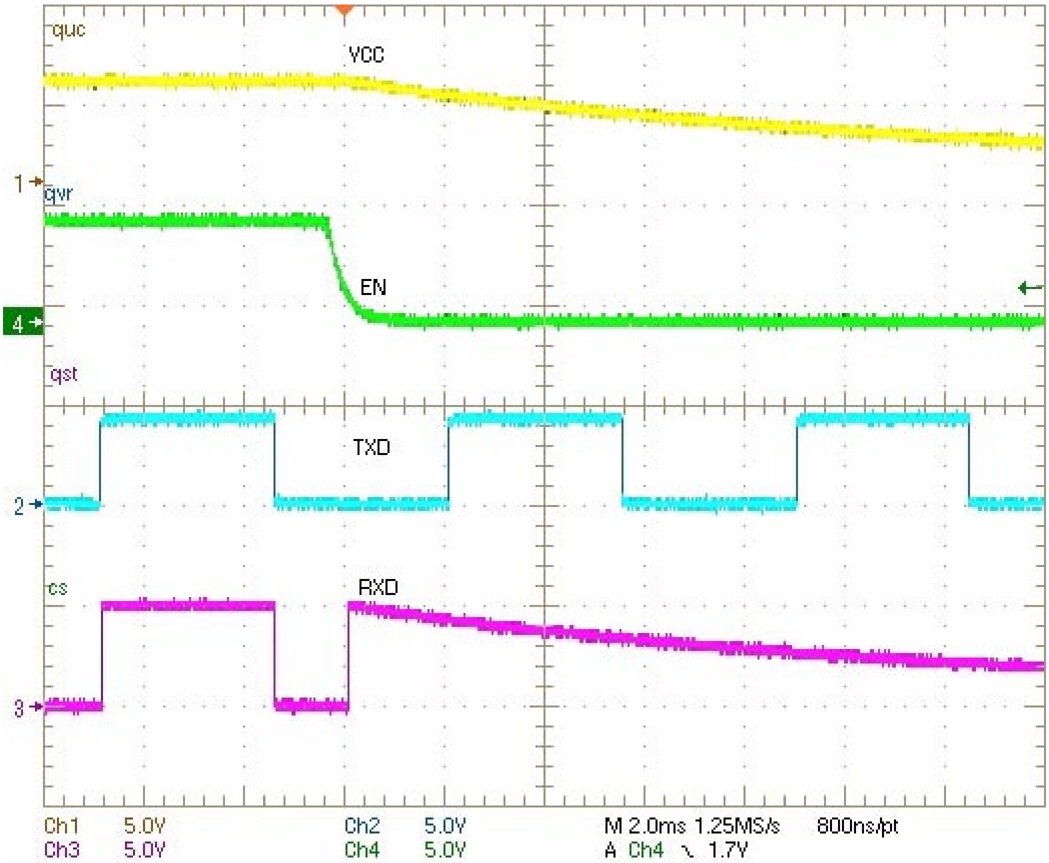


Figure 17 Measurement: mode change from Normal Operation Mode to Sleep Mode

When the TLE8457 changes the mode of operation from Normal Operation Mode to Sleep Mode, it blocks the transmitter and sets the RxD output to "high". RxD then follows the V_{CC} voltage. The immediate deactivation of the transmitter ensures, the LIN bus is not disturbed during mode changes from Normal Operation Mode to Sleep Mode. In Sleep Mode the V_{CC} internal voltage regulator is disabled. An internal pull-down resistor discharges the V_{CC} output in Sleep Mode.

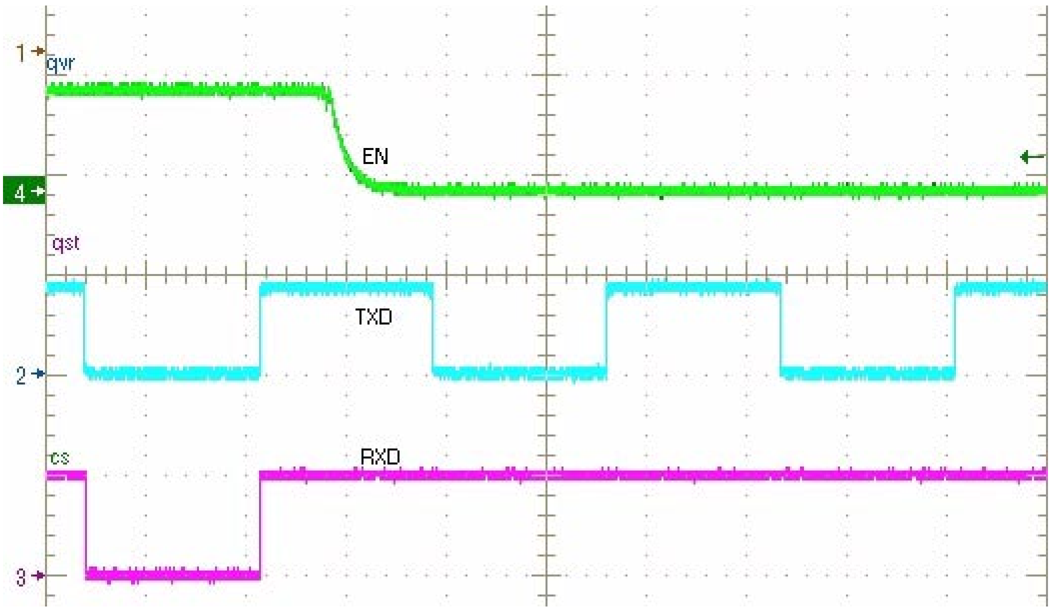


Figure 18 Measurement: mode change from Normal Operation Mode to Stand-by Mode

When the TLE8457 changes the mode of operation from Normal Operation to Stand-by Mode, it blocks the transmitter and it sets RxD to “high”. The immediate deactivation of the transmitter ensures, the LIN bus is not disturbed during mode changes from Normal Operation Mode to Stand-by Mode. The V_{CC} voltage regulator remains active in Stand-by Mode.

5.2.2.1 Sleep Mode to Normal Operation Mode

A mode change by the EN pin from Sleep Mode to Normal Operation Mode is only possible via Init Mode. In Sleep Mode the EN pin is set to “low”. A “high” signal on EN pin triggers a mode change to Init Mode. In Init Mode the V_{CC} voltage regulator ramps up. If $V_{CC} > V_{CC,UV}$ and EN = “high”, then this will trigger a mode change to Normal Operation Mode. Normal Operation Mode is entered after t_{RST}. In Normal Operation Mode the TLE8457 releases the transmitter, drives the data stream on the TxD input pin to the LIN Bus and reflects it on the RxD output pin.

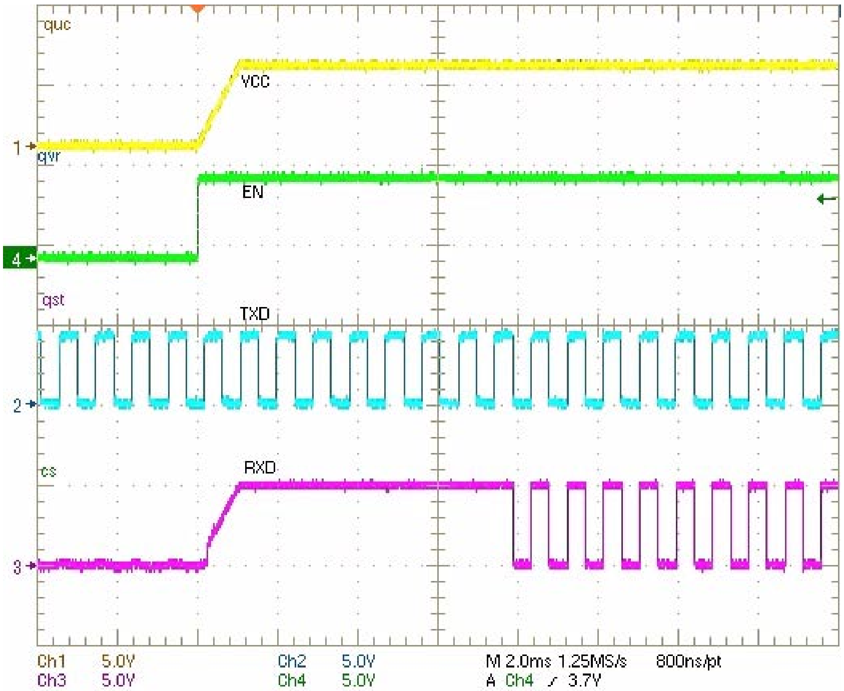


Figure 19 Measurement: mode change from Sleep Mode to Normal Operation Mode

5.2.2.2 Stand-by Mode to Normal Operation Mode

In Stand-by Mode the EN input pin is set to “low”. A rising edge on the EN input pin triggers a mode change from Stand-by Mode to Normal Operation Mode. In Normal Operation Mode the TLE8457 releases the transmitter, drives the data stream on the TxD input pin to the LIN Bus and reflects it on the RxD output pin.

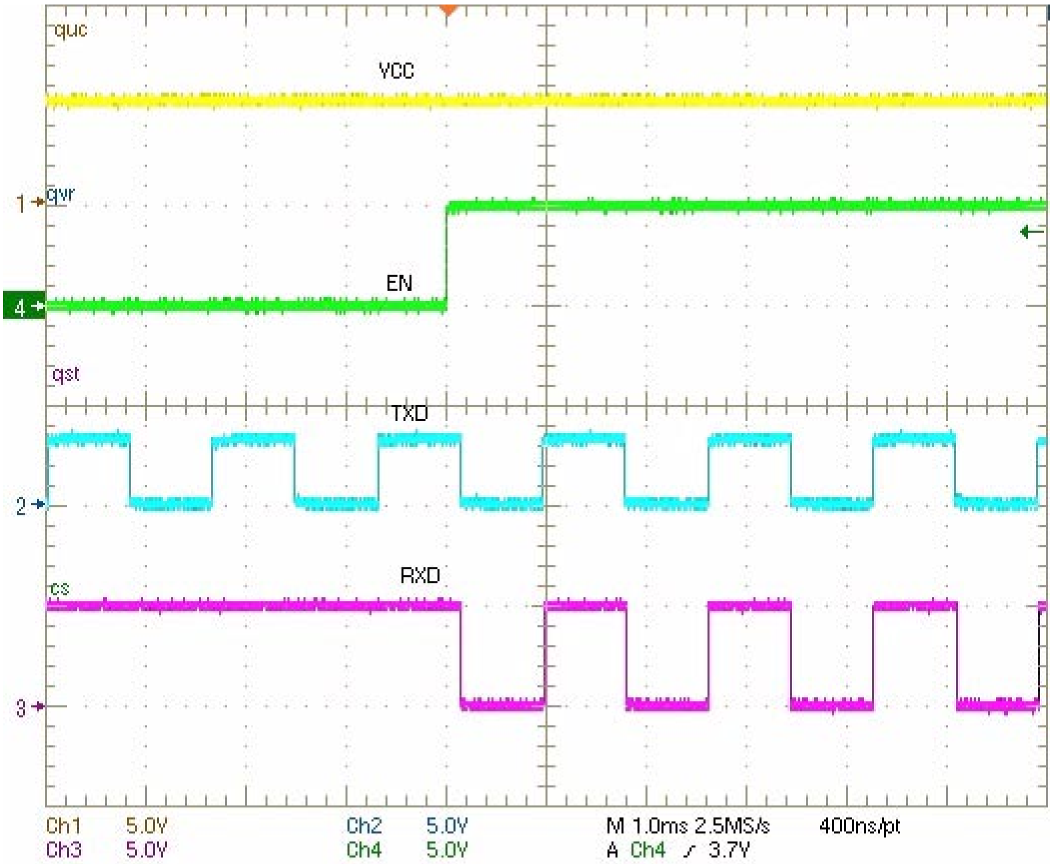


Figure 20 Measurement: mode change from Stand-by Mode to Normal Operation Mode

5.3 Initialization Watchdog Time-out measurements

The Initialization Watchdog is only active in Init mode. The Initialization Watchdog can detect local failures and handle errors for minimizing system current consumption. The benefit lies in preventing the vehicle battery from draining due to a malfunctioning ECU, which is stuck in Init mode with high current consumption. If an Initialization Watchdog Time-out is detected, then this forces a mode transition to Sleep Mode in order to minimize the current consumption in the following conditions:

- V_{CC} supply initialization failure
- Normal Operation Mode activation failure

5.3.1 V_{CC} undervoltage behavior

The V_{CC} supply Initialization Watchdog detects local errors on the ECU that prevent the V_{CC} supply from powering up correctly, either due to a short circuit to GND or due to excessive current consumption by any component on the board.

The V_{CC} supply Initialization Watchdog timer starts in the following cases:

- the linear regulator is switched on after a power-up event
- a mode transition to Init Mode, triggered by a bus wake-up event
- a mode transition to Init Mode, triggered by the EN input set to “high” in Sleep Mode or Stand-by Mode
- on V_{CC} undervoltage
- recovery from an overtemperature event

If V_{CC} is below the $V_{CC,UV}$ undervoltage threshold when the timer t_{Init_WD} elapses, then the TLE8457 enters Sleep mode (see **Figure 21**). If V_{CC} is above the $V_{CC,UV}$ undervoltage threshold before the Initialization Watchdog timer t_{Init_WD} elapses, then the TLE8457 disables the Initialization Watchdog timer.

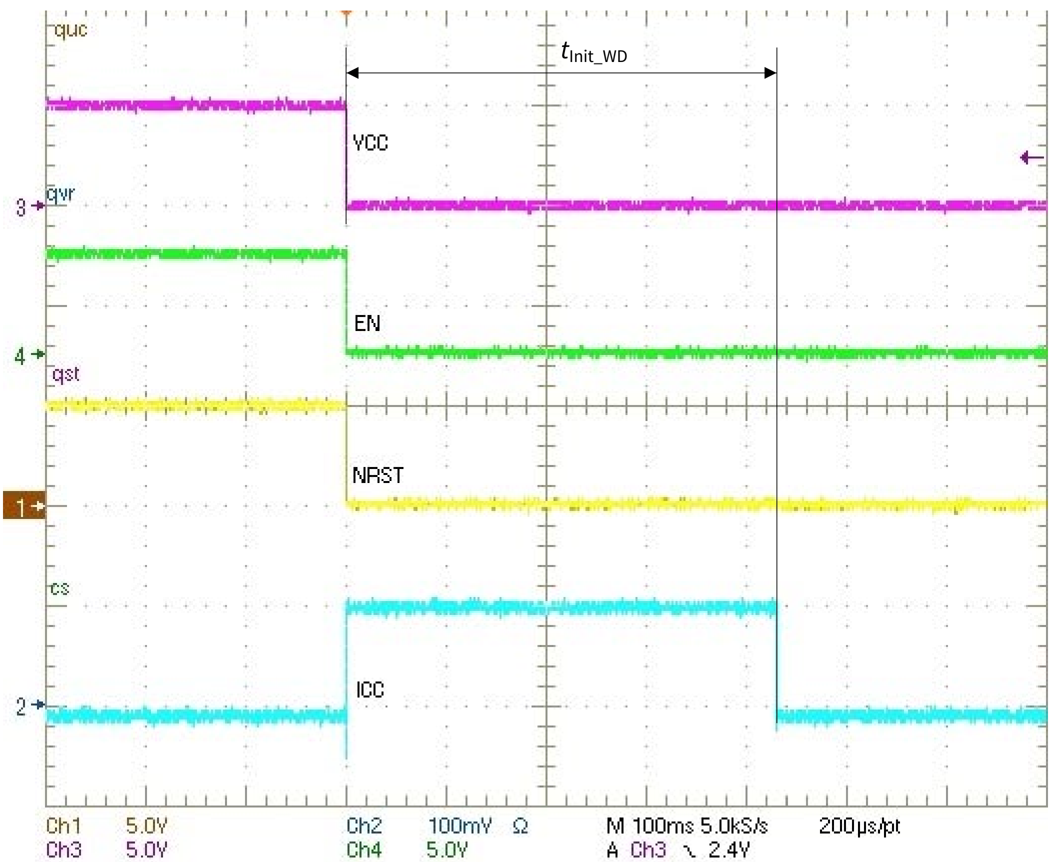


Figure 21 Measurement: power-up sequence with Watchdog Initialization Time-out

5.3.2 EN time-out behavior

After first powering up the TLE8457, or after a reset pulse on V_S, the Initialization Watchdog timer monitors monitoring the activation of Normal Operation mode. If the microcontroller fails to set the EN input "high" before the timer t_{Init_WD} elapses, then the TLE8457 enters Sleep Mode (see **Figure 22** and **Figure 23**).

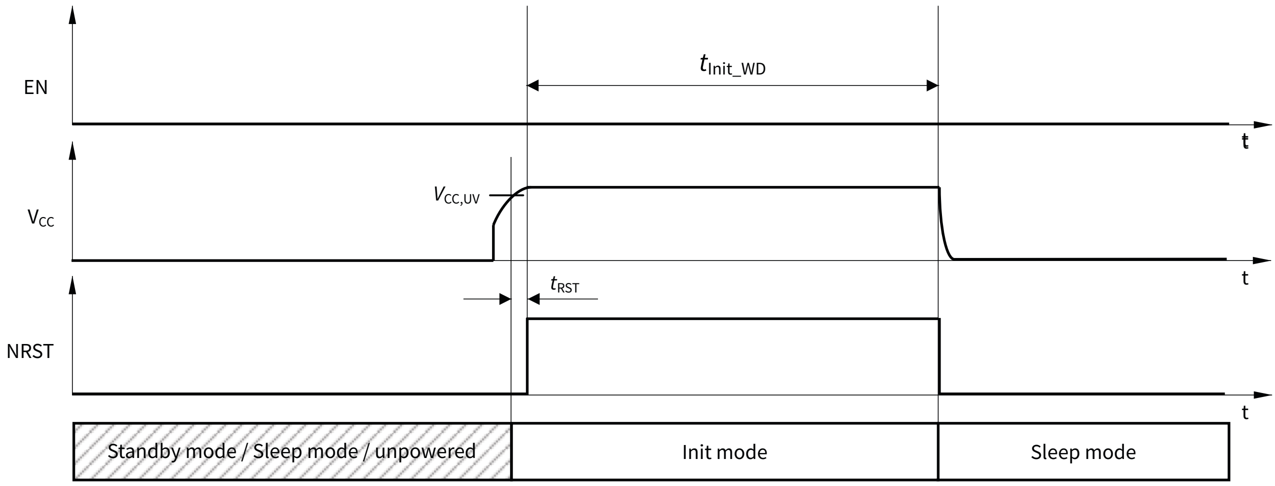


Figure 22 Normal Operation Mode activation time-out

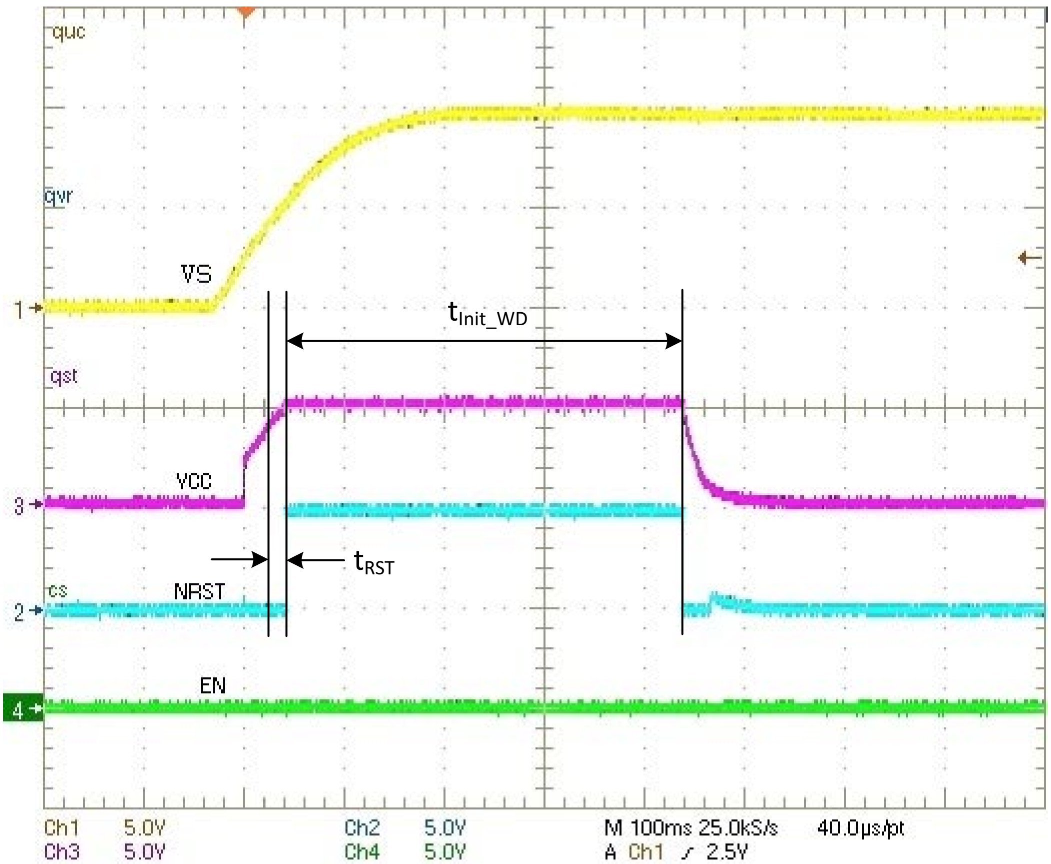


Figure 23 Measurement: power-up sequence with Normal Operation Mode activation time-out

5.4 Power-up sequence

The following figures show flow diagrams of the recommended power-up sequences for:

- the start-up phase of the TLE8457 (see **Figure 24**)
- a wake-up event in Stand-by Mode (see **Figure 25**)
- a wake-up event in Sleep Mode (see **Figure 26**)

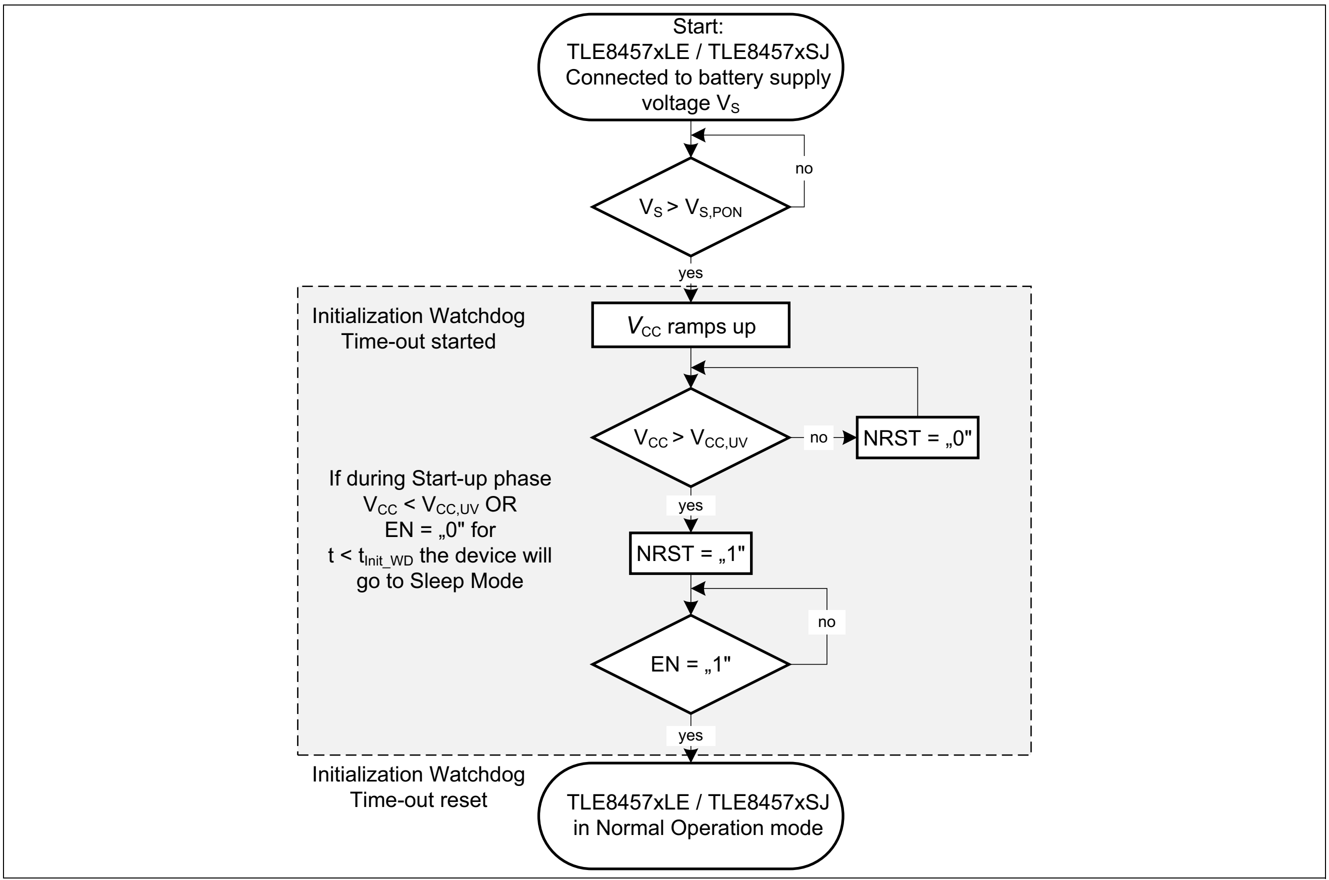


Figure 24 Power-up sequence during Start-up Phase

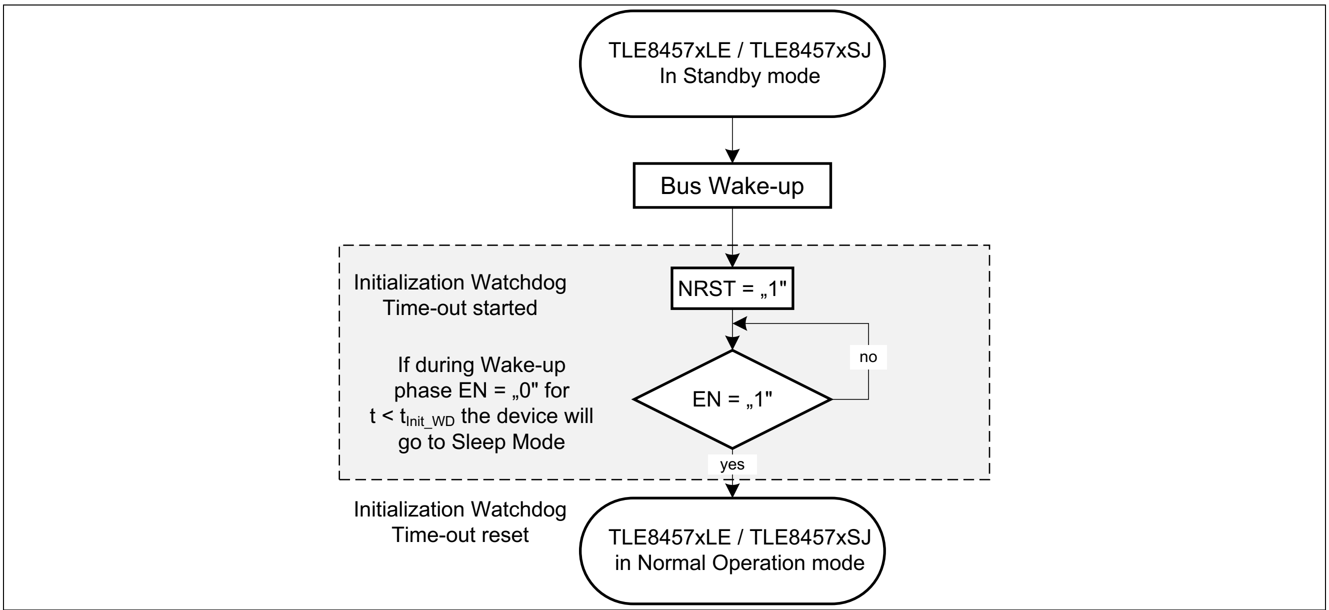


Figure 25 Power-up sequence after a bus wake-up event in Stand-by Mode

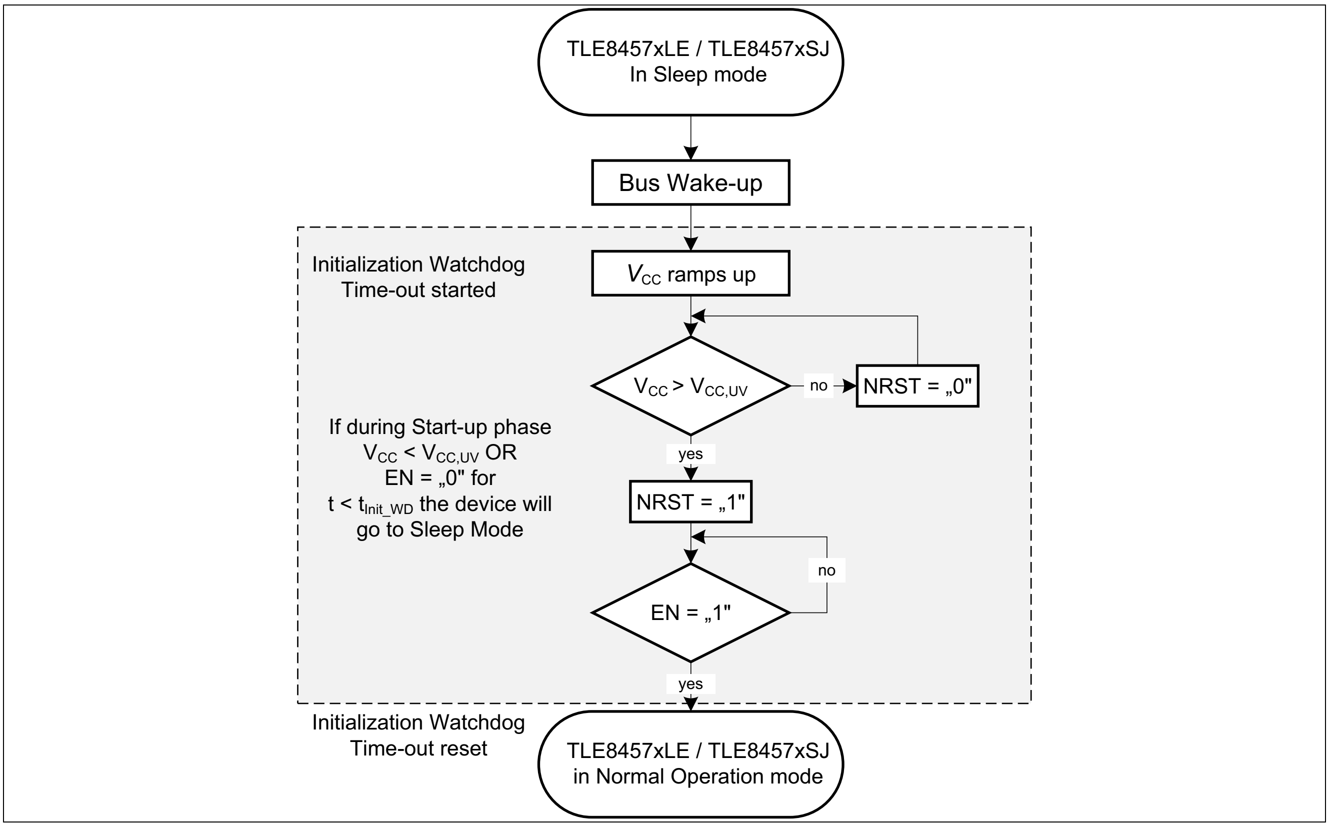


Figure 26 **Power-up sequence after a bus wake-up event in Sleep Mode**

5.5 Application scenarios outside specified operating range

This chapter includes behavioral description of TLE8457 for scenarios, which are outside the specified operating range and beyond typical application usage.

5.5.1 V_S unconnected and V_{CC} output pin forced to 5V

Typically the V_{CC} output pin of TLE8457 is used to supply the microcontroller. During programming phase of an ECU, the microcontroller may be supplied by an external supply voltage, not using the V_{CC} output voltage of TLE8457 by leaving battery supply unconnected.

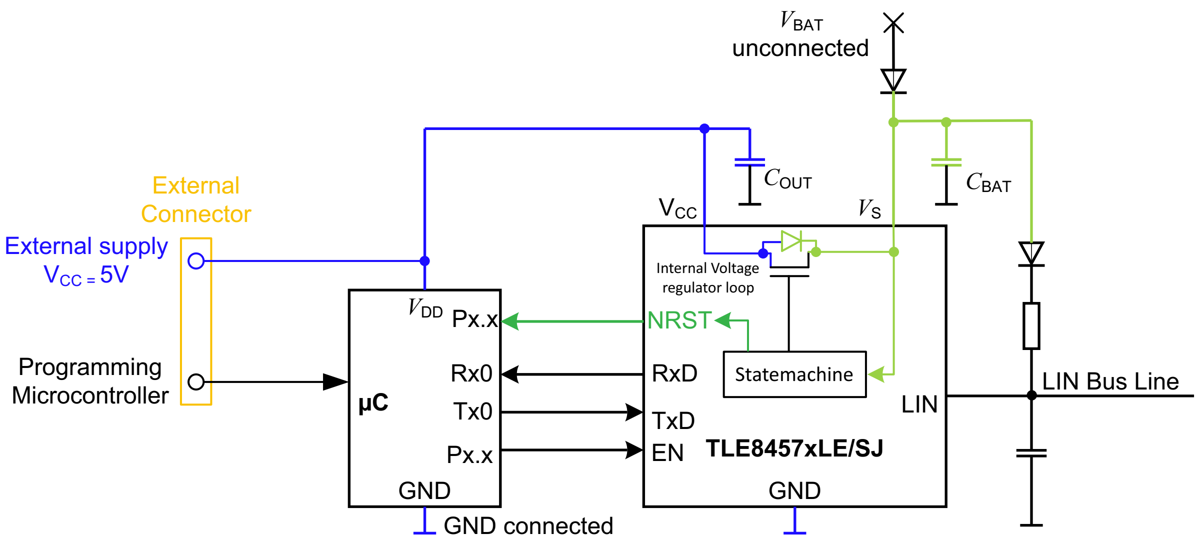


Figure 27 **TLE8457 with unconnected V_S pin and forced 5V on V_{CC} pin**

In this case the V_{CC} output pin of TLE8457 is used as an supply input pin, which means TLE8457 is reversely supplied to the original supply purpose via V_S. The TLE8457 gets active with V_S unconnected and V_{CC} forced to 5V from outside. The reason is a PMOS Transistor in the LDO output stage of the V_{CC} of TLE8457. Through the internal body diode of the PMOS Transistor V_S pin gets charged and the statemachine of TLE8457 ramps up. As mentioned previously this scenario may occur during programming phase of an ECU, when connecting an external V_{CC} supply. In this case a defined and deterministic behavior of the NRST output pin of TLE8457 is getting important in order not to block or to reset the microcontroller during programming phase. Therefore the behavior of the TLE8457 and the NRST output pin (V_S unconnected, V_{CC} = 5V) is described in this chapter in more detail:

Scenario 1: V_{CC} = 5V, EN = “high”=> TLE8457 enters Normal Operation Mode through Init Mode, NRST = “high”.

Scenario 2: V_{CC} = 5V, EN = “low”=> TLE8457 enters Init Mode (NRST = “high”), and then Sleep Mode (NRST = “low”).

Scenario 3: WhenTLE8457 is in Normal Operation Mode (Scenario 1), and then EN = “low” while TxD = “high”, TLE8457 goes to Stand-by Mode (NRST = “high”).

Scenario 4: When TLE8457 is in Normal Operation Mode (Scenario 1), and then EN = “low” while TxD = “low”, TLE8457 goes to Sleep Mode (NRST = “low”).

Scenario 5: When TLE8457 is in Sleep Mode (Scenario 2), and EN = 1, while V_{CC} = 5V, the device remains in Sleep Mode. This the recommended behavior for typical application scenario when V_S is connected. Typically TLE8457 supplies the microcontroller. This means first V_{CC} has to ramp up, then EN has to be set to “high” from the microcontroller. If it is vice versa, the transition to Init Mode is blocked and TLE8457 remains in Sleep Mode.

Scenario 6: When TLE8457 is in Sleep Mode (Scenario 2), and a Bus Wake-up is monitored AND EN = “low”, TLE8457 goes via Init Mode (NRST = “high”) back to Sleep Mode (NRST = “low”).

Scenario 7: When TLE8457 is in Sleep Mode (Scenario 2), and a Bus Wake-up is monitored AND EN = “high”, TLE8457 goes via Init Mode to Normal Operation Mode (NRST = “high”).

If there are other external components connected on V_S of TLE8457, additional current will be drawn through V_{CC} to V_S. As in this configuration the TLE8457 is operating in reverse direction (which is not recommended and not the application purpose) this will heat up the device which can results in high stress to TLE8457 and to the external connector.

6 Failure Management

This chapter describes fail-safe features of the TLE8457.

6.1 Initialization Watchdog Time-out feature

The Initialization Watchdog is only active in Init mode. The Initialization Watchdog can detect local failures and handle errors for minimizing system current consumption. The benefit lies in preventing the vehicle battery from draining due to a malfunctioning ECU, which is stuck in Init mode with high current consumption. The Initialization Watchdog timer t_{Init_WD} starts at each of the following events:

- after power-up (1)
- after bus wake-up detection (2), (3)
- on a mode change triggered by the EN input pin (4)
- on V_{CC} undervoltage detection (5), (6)
- recovery from overtemperature event on voltage regulator (7)

If an Initialization Watchdog Time-out is detected, then this will force a mode change to Sleep Mode (see **Figure 28**). **Chapter 5.3** shows details and measurements.

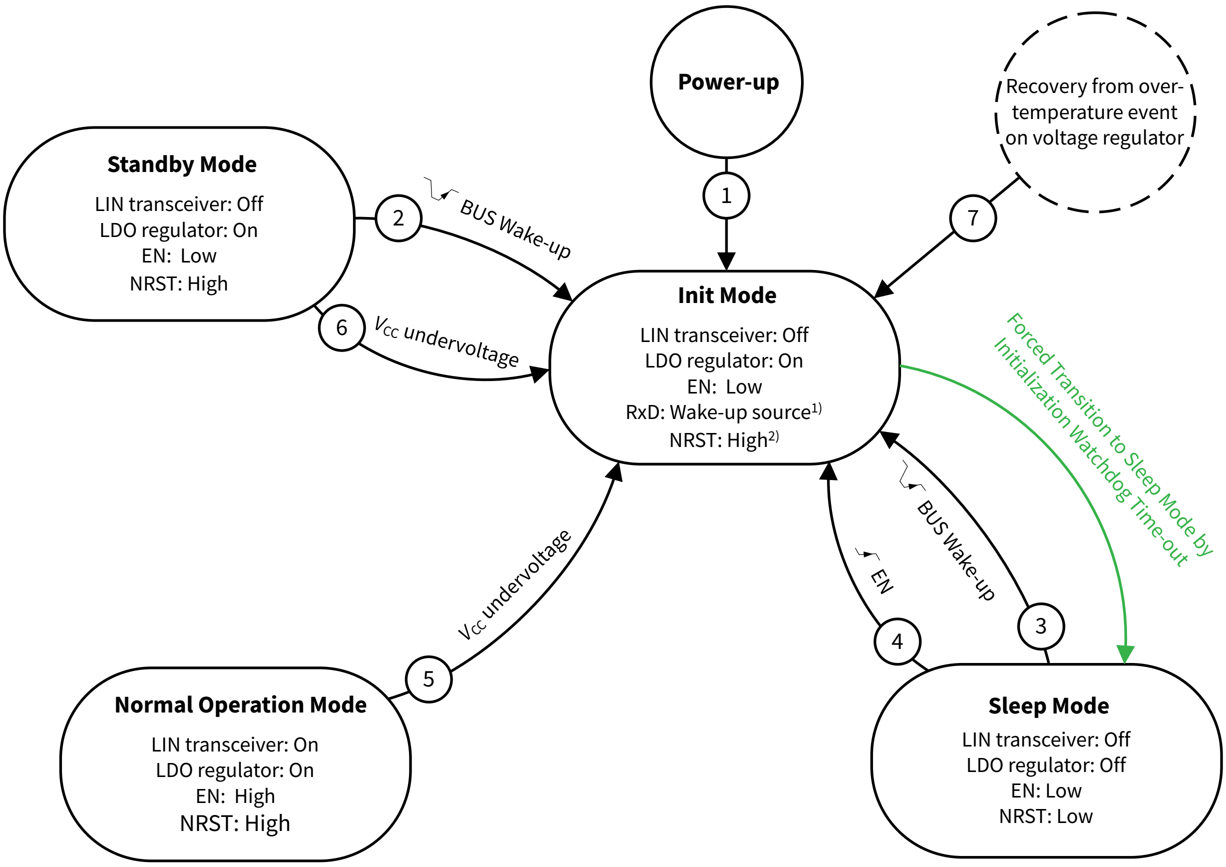


Figure 28 Mode diagram with Initialization Watchdog Time-out Feature

6.2 TxD dominant time-out detection

The TxD dominant time-out detection is enabled in Normal Operation Mode. If a TxD pin is shorted to ground, usually that would clamp the LIN bus to the dominant level, which blocks any transmission on the LIN bus. If the TxD input persists dominant for at least t_{TXD}, then the TLE8457a detects a TxD dominant failure. When the TLE8457 detects a TxD dominant failure, then it disables the transmitter, so the LIN bus is released. This fail-safe feature is implemented in order to not block permanently the communication on the LIN bus. A recessive level on the TxD pin for $t > t_{to,rec}$ (max. 10µs) resets the TxD dominant timer. As a consequence, transmission speed on the LIN bus must exceed the minimum baud rate in order not to trigger the TxD dominant time-out feature.

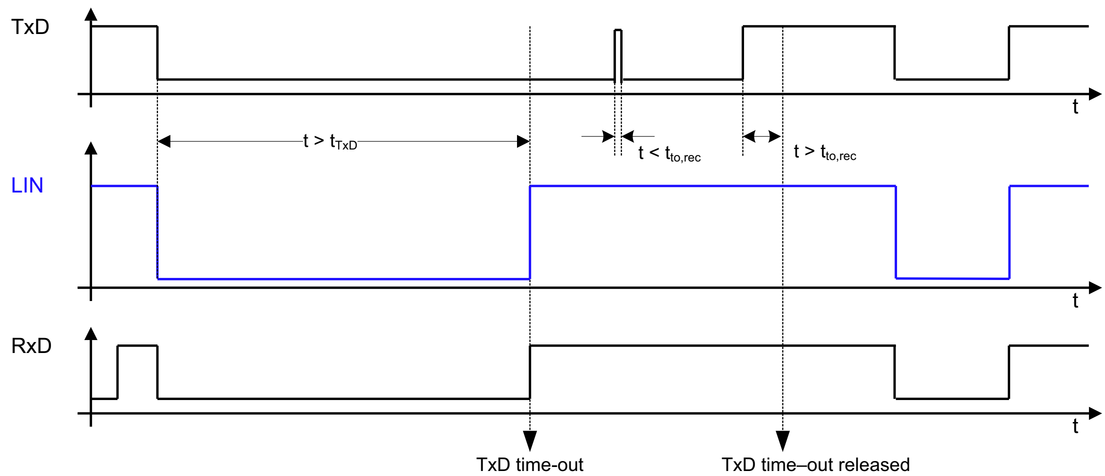


Figure 29 Resetting TxD dominant time-out detection

6.2.1 Short circuit on V_{CC} pin

Figure 30 shows the short circuit types on the V_{CC} output pin:

- V_{CC} shorted to GND (Case 1):
  If a short circuit of V_{CC} pin to GND occurs in Normal Operation Mode, then the TLE8457 enters Init Mode. If the short circuit persists in Init Mode, then the Initialization Watchdog Time-out is triggered (see **Chapter 6.1**) and the TLE8457 enters Sleep Mode. This fail-safe behavior protects the TLE8457 from heating up due to a permanent short circuit current. The transition to Sleep Mode and the switching off of the V_{CC} output, save battery current, extending overall battery lifetime.
- V_{CC} shorted to V_S (Case 2):
  The violation of the absolute maximum ratings specified in the data sheet damages the TLE8457.

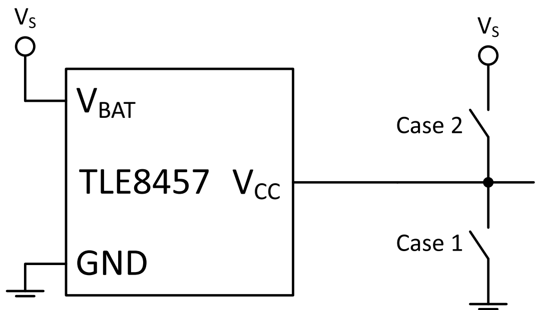


Figure 30 V_{CC} short circuit types

6.2.2 Short circuit on the LIN bus

Figure 31 shows the short circuit types on the LIN bus:

- LIN bus pin shorted to GND (Case 1)
- LIN bus pin shorted to V_S (Case 2)

The LIN bus pin is short circuit proof to GND as well as to supply voltage. A current limiting circuit protects the TLE8457 from damage. If the TLE8457 heats up due to a permanent short at LIN pin, then the overtemperature protection disables the transmitter. A LIN bus short circuit to GND or battery supply blocks communication on the LIN bus.

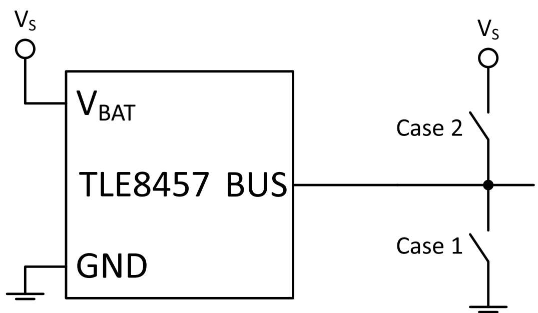


Figure 31 LIN bus short circuit types

In Sleep Mode a short circuit on the LIN bus is not recognized as a wake-up event and does not trigger a mode change to Stand-by Mode.

7 Integrated Low Drop Output Voltage Regulator

The TLE8457 has an integrated Low Drop Output (LDO) voltage regulator:

TLE8457ASJ/TLE8457ALE: 5 V voltage regulator and the “B”-variant has a 3.3 V voltage regulator.

The integrated voltage regulator can supply external components, for example a microcontroller. With a minimum current capability of 70 mA, the TLE8457 covers almost every possible application. The internal pull-down resistor (typically 50 kΩ) from the V_{CC} pin to GND discharges the output capacitor, when the TLE8457 enters Sleep Mode and the internal voltage regulator is switched off. **Table 2** shows the major benefits of the integrated high performance LDO voltage regulator.

Table 2 Customer benefits of the TLE8457

Parameter	Symbol	min	max	Unit	Benefit	No. in Datasheet
V_{CC} output voltage range	V_{CC}	4.9	5.1	V	Narrow voltage range window ensures stable V_{CC} output voltage for safe and smooth application usage.	P_6.1.23
V_{CC} output current limitation	$I_{CC,lim}$	–	150	mA	In case of a short circuit on V_{CC}, the output current is limited to max. 150 mA. This reduces extreme thermal stress conditions for the chip and the package in case of a short circuit. Reducing the thermal stress results in higher reliability of the device.	P_6.1.27, P_6.1.39
Current consumption in Sleep Mode	$I_{S,sleep}$	–	16	µA	Best-in-Class ultra low quiescent current in Sleep Mode and Stand-by Mode. In Sleep Mode and Stand-by Mode a very low current consumption is most important in order to save battery current. See **Table 3** for details on current consumption for different temperature ranges.	P_6.1.5
Current consumption in Stand-by Mode	$I_{S,standby}$	–	40	µA		P_6.1.4
Stabilization output capacitor on VCC	C_{VCC}	1	–	µF	Only 1 µF capacitor is needed for stable and robust performance in the application. This enables the placement of small sized capacitor on the PCB, which results in PCB board savings and system cost savings.	P_5.2.3
PSRR (Reduction Ratio)	PSRR	50	60	dB	For automotive applications it is important to dampen the coupled noise through battery supply to the external voltage supply on V_{CC}. Therefore TLE8457 offers a PSRR noise reduction ratio from V_S to V_{CC} of minimum 50 dB.	P_6.1.30
Load regulation	$\Delta V_{CC,lo}$	–	50	mV	Guaranteed maximum voltage shift for wide current load profiles for stable V_{CC} voltage output during application start-up phases.	P_6.1.28, P_6.1.39
Line regulation	$\Delta V_{CC,li}$	–	50	mV	Guaranteed maximum voltage shift for wide battery voltage ranges for stable V_{CC} voltage independent on the battery voltage profile.	P_6.1.29, P_6.1.40

7.1 V_{CC} undervoltage detection and response time

The V_{CC} pin is the voltage regulator output. The V_{CC} pin can supply external components, for example a microcontroller. The integrated high performance voltage regulator can drive a current of minimum 70 mA. An external stabilization capacitor of only 1 µF is necessary for a stable and robust supply output voltage. Therefore system cost saving on ECU level can be achieved. A ceramic capacitor is recommended, due to their low ESR. **Chapter 4.8** shows a typical V_{CC} voltage regulator circuitry.

The NRST output pin indicates the status of the voltage regulator. The TLE8457 has undervoltage detection on the voltage regulator. If V_{CC} falls below the undervoltage threshold $V_{CC,UV}$ for longer than detection time $t_{det,RST}$, then the NRST output is set to “low”. If recovery from the failure is completed and reset time t_{RST} elapses after that, then NRTS changes to “high” (see **Figure 32** and **Figure 33**).

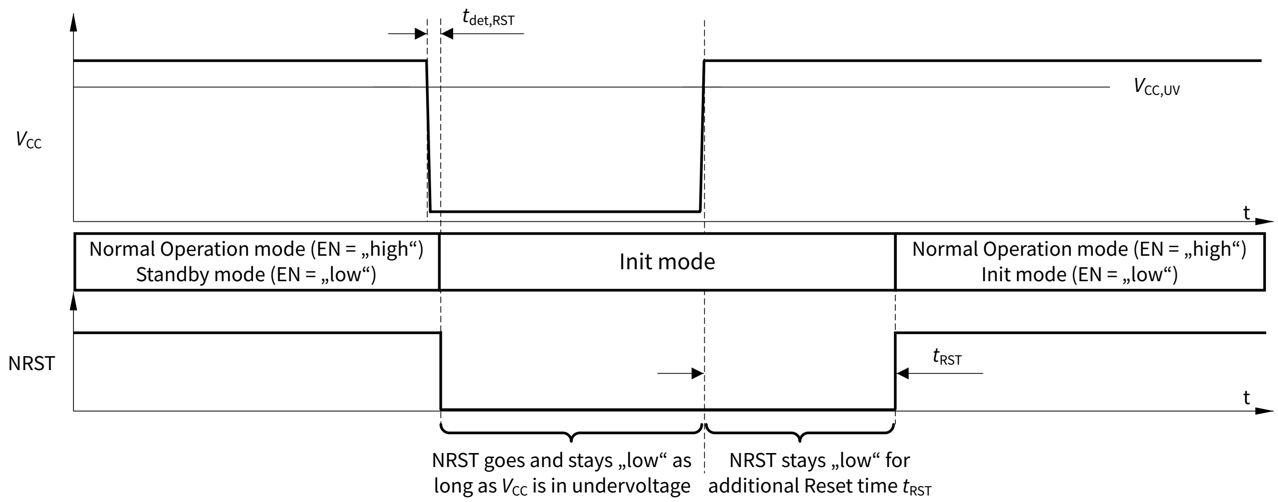


Figure 32 V_{CC} **undervoltage detection and recovery**

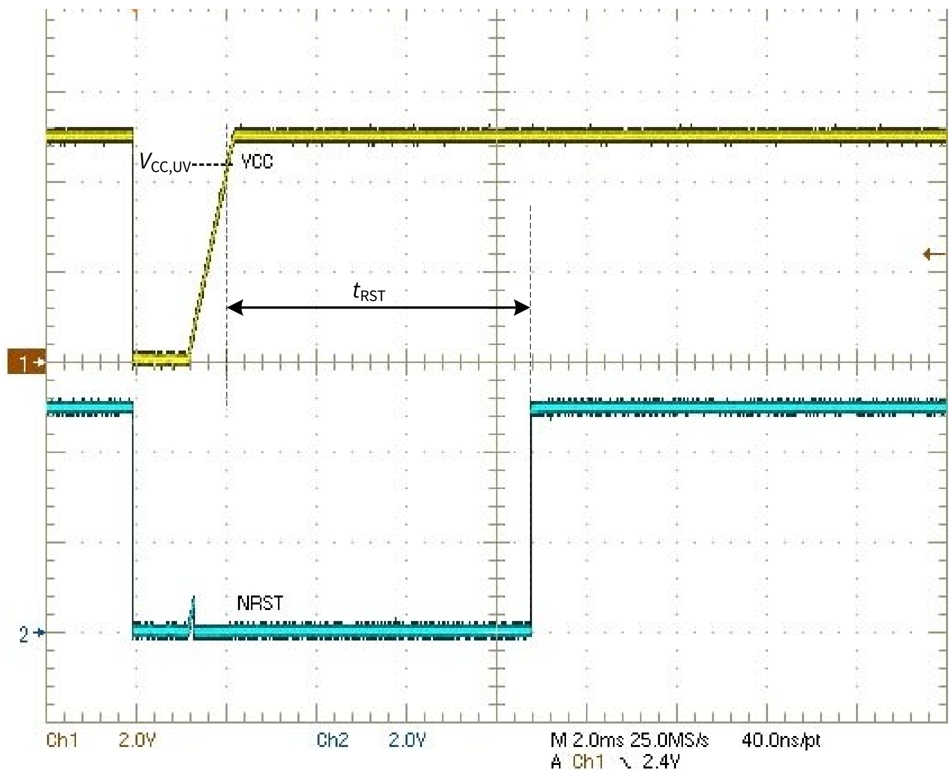


Figure 33 **Example measurement** V_{CC} **undervoltage detection and recovery**

7.2 Load jump measurement example

This chapter describes an example measurements with TLE8457A (5V - Version). The internal voltage regulator is enabled in Normal Operation Mode. As a base load R_{L1} = 500Ω is place at V_{CC} output to draw I_{L1} = ~10mA. In parallel an additional load R_{L2} = 100Ω is connected via a switch to draw additional current of I_{L2} = 50mA. R_{L2} is connected and disconnected cyclically in order to simulate load jumps on V_{CC} output. This test is intended to show the fast load regulation of the internal V_{CC} voltage regulator during rapidly changing load profiles. Unwanted oscillations on V_{CC} output are attenuated and only little over- and undershoot voltages are monitored.

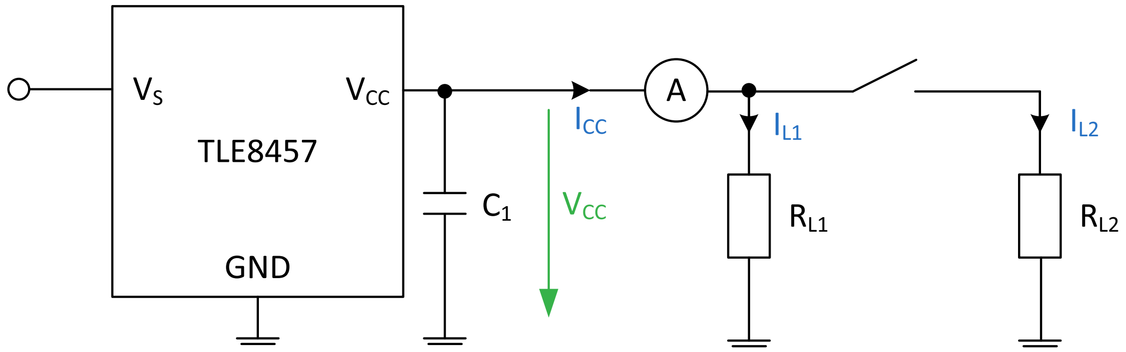


Figure 34 Load jump test circuit

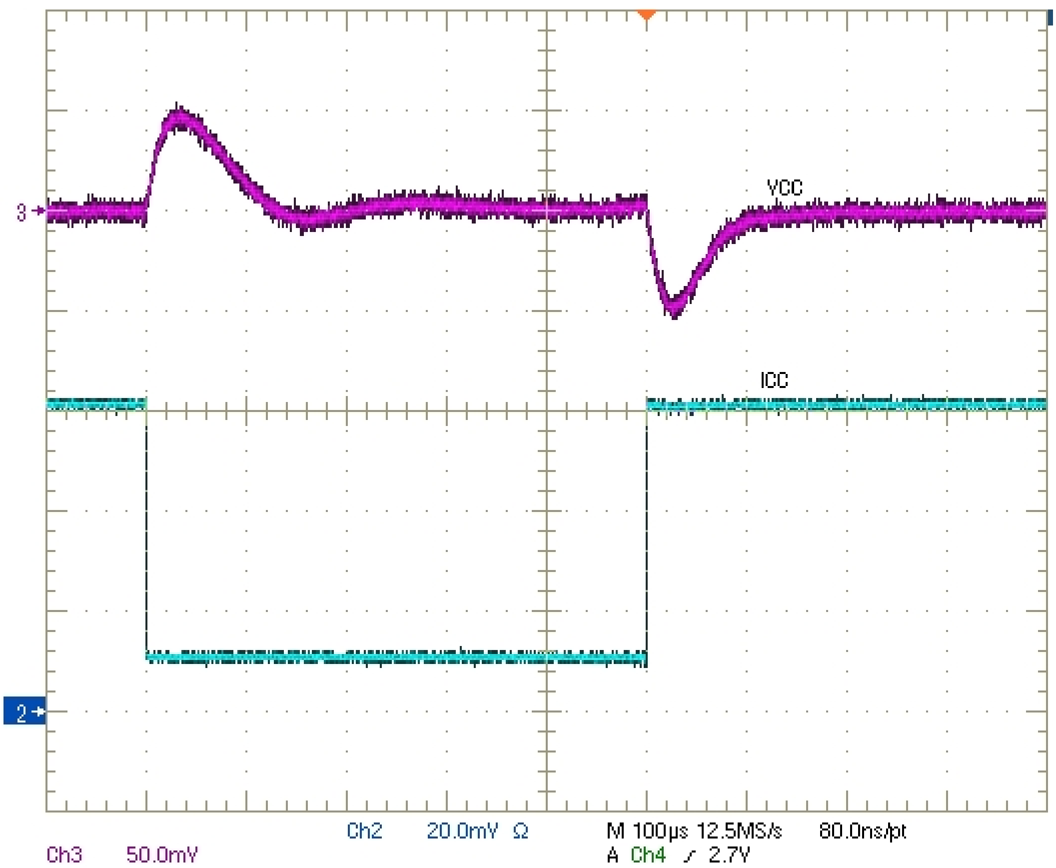


Figure 35 Load jump measurement example with TLE8457A

7.3 V_S ramp up example measurement

TLE8457 will enter Stand-by Mode already when applying a very low input voltage of $V_{S,PON}$ > 3V. In Stand-by Mode the internal voltage regulator is turned on. For low V_S input voltage 5.5V > V_S > 3.0V the voltage regulator is in so called "tracking mode". In this mode the V_{CC} output follows the V_S input voltage with a very low voltage drop V_{DR}, until the final output voltage of the voltage regulator is reached (TLE8457A: 5V, TLE8457B: 3.3V). The very low voltage operation capability of TLE8457 with V_S > 3.0V can be an advantage in certain applications. Due to the fact TLE8457 enables the V_{CC} output voltage at low V_S voltage, externally by V_{CC} supplied devices (e.g. microcontroller) can start to ramp-up and operate earlier then with other common devices. Additionally for battery cranking scenarios, the TLE8457 does not switch off the voltage regulator for V_S > 3.0V, which ensures a more reliable and robust behavior within the application. The internal voltage regulator of TLE8457 is characterized by its very low drop voltage $V_{DR} = V_S - V_{CC}$, which results in higher reliability for low V_S voltage scenarios.

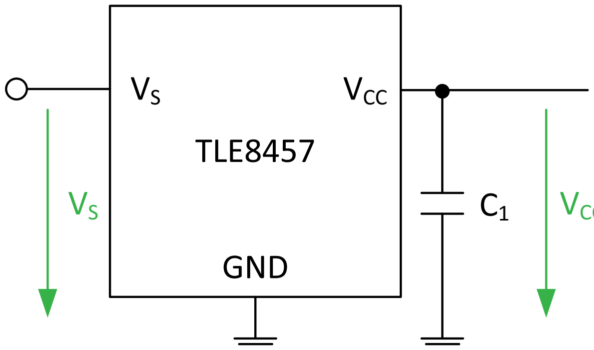


Figure 36 **V_S ramp up test setup**

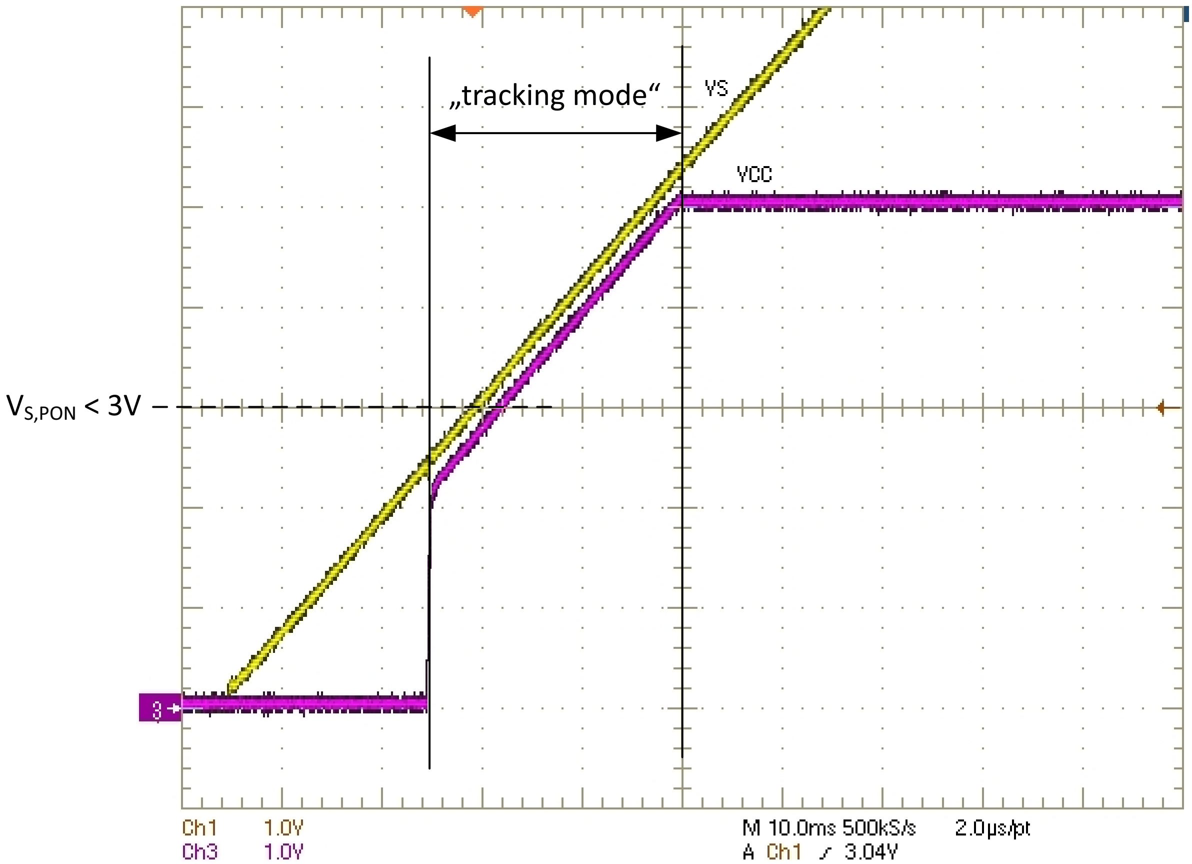


Figure 37 **TLE8457A example measurement: Tracking Mode of V_{CC} during V_S ramp up**

8 Power consumption aspects

The TLE8457 is designed for low system power consumption, which is a key feature for LIN transceivers with integrated voltage regulator.

Despite extremely low system power consumption the TLE8457 provides full wake-up capability via the LIN bus, maintaining high immunity against electromagnetic disturbance.

Table 3 Current consumption in low-power modes

Mode of operation	Current consumption I_S @ V_S = 13.5V						Unit
	@25°C		@85°C		@150°C		
	typ.	max.	typ.	max.	typ.	max	
Sleep Mode	7	10	8	12	11	16	µA
Stand-by Mode	21	24	23	27	28	40	µA

8.1 Sleep Mode current consumption

The TLE8457 provides a minimized very low current consumption in Sleep Mode of max. 18 µA. If the transceiver supplies an ECU from the integrated voltage regulator via V_{CC}, the only remaining system current flows into the V_S pin.

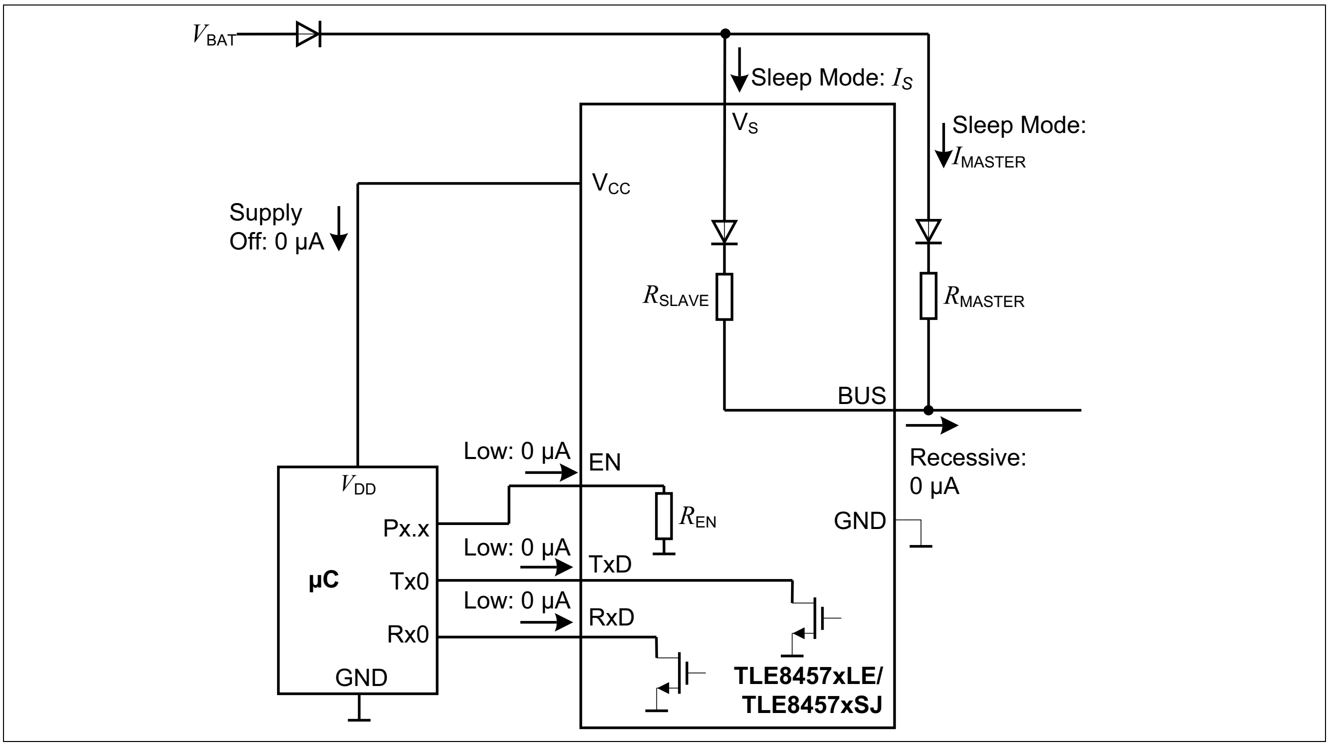


Figure 38 Current consumption in Sleep Mode

8.2 Sleep Mode power consumption during LIN bus short circuit

If LIN is shorted to ground, then the external master termination resistor and the internal pull up termination resistors of all slaves determine the power consumption of the TLE8457. The TLE8457 does not wake up nor change into Stand-by Mode, but remains in Sleep Mode to reduce the overall power consumption.

8.3 Stand-by Mode power consumption

The TLE8457 provides a minimized very low current consumption $I_{S,Standby}$ in Stand-by Mode of max. 40 µA. If the transceiver supplies an ECU from the integrated voltage regulator via V_{CC}, an additional current I_{CC} flows through V_S to supply V_{CC}.

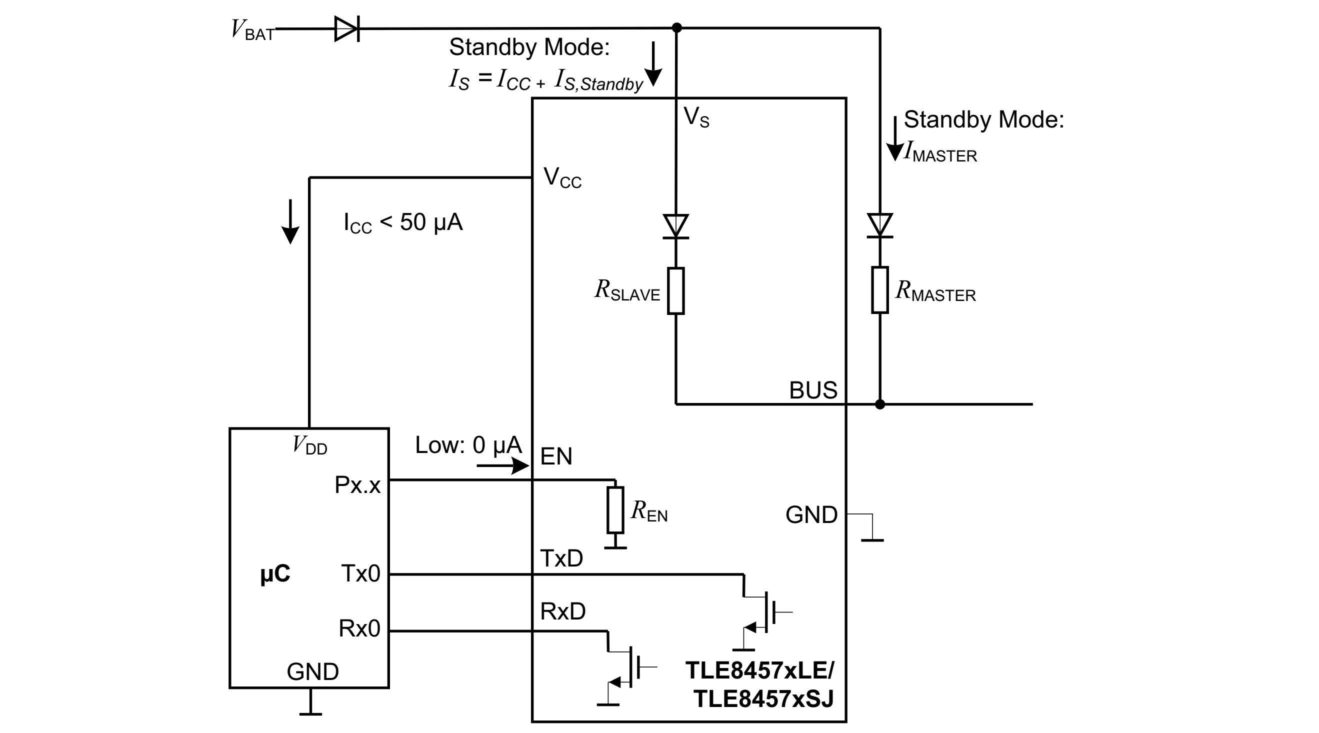


Figure 39 Current consumption in Stand-by Mode

8.4 Power dissipation - Safe Operating Area

The linear regulator drop, V_S - V_{CC}, and the output current I_{VCC} mainly determine the power dissipation of the TLE8457xLE, TLE8457xSJ. The safe operating area of the TLE8457 in a DSO-8 package with R_{thJA} = 130 K/W is given and for TSON-8 package with R_{SthJA} of 70 K/W is given. Care must be taken to ensure that the TLE8457xLE, TLE8457xSJ is operating within the maximum ratings in the application.

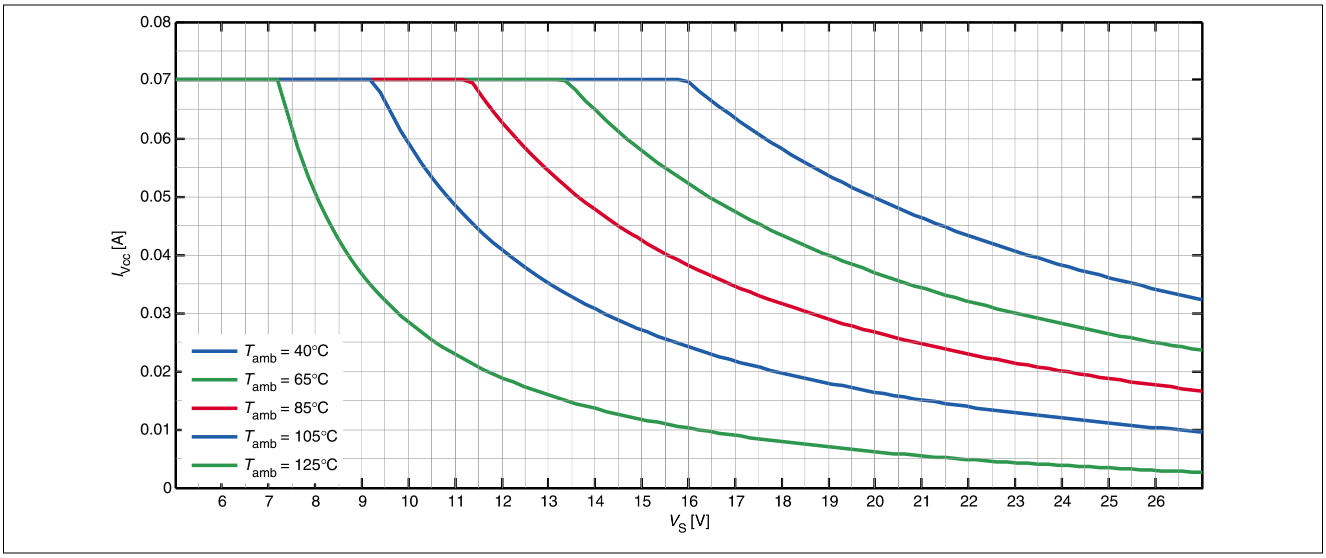


Figure 40 Safe operating area TLE8457ASJ (5 V LDO, PG-DSO-8 package)

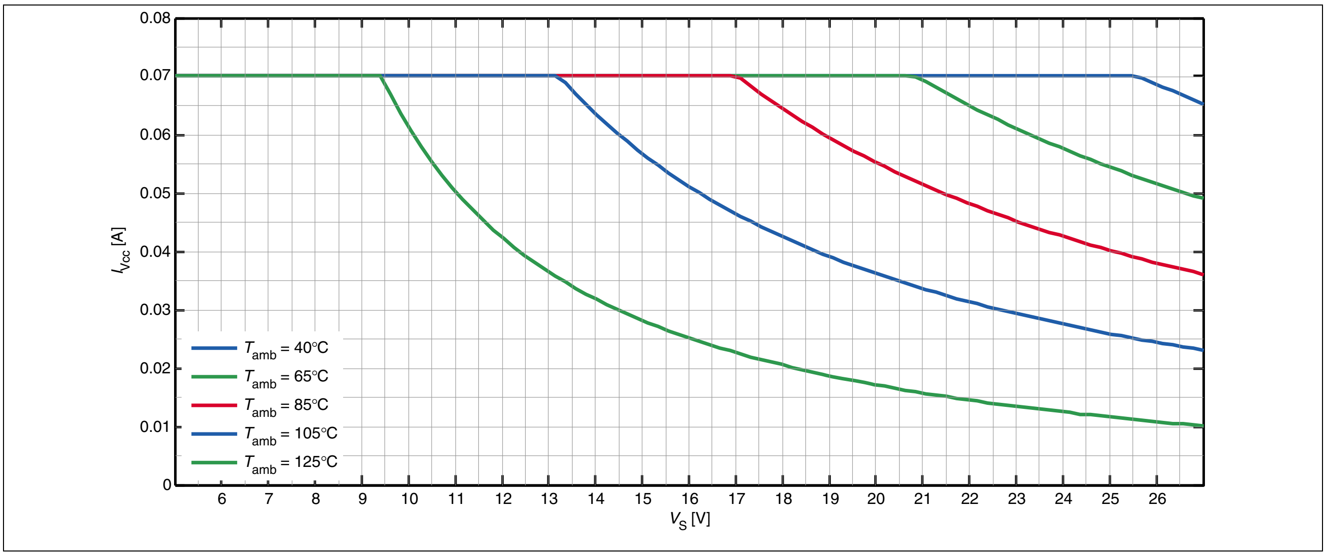


Figure 41 Safe operating area TLE8457ALE (5 V LDO, PG-TSON-8 package)

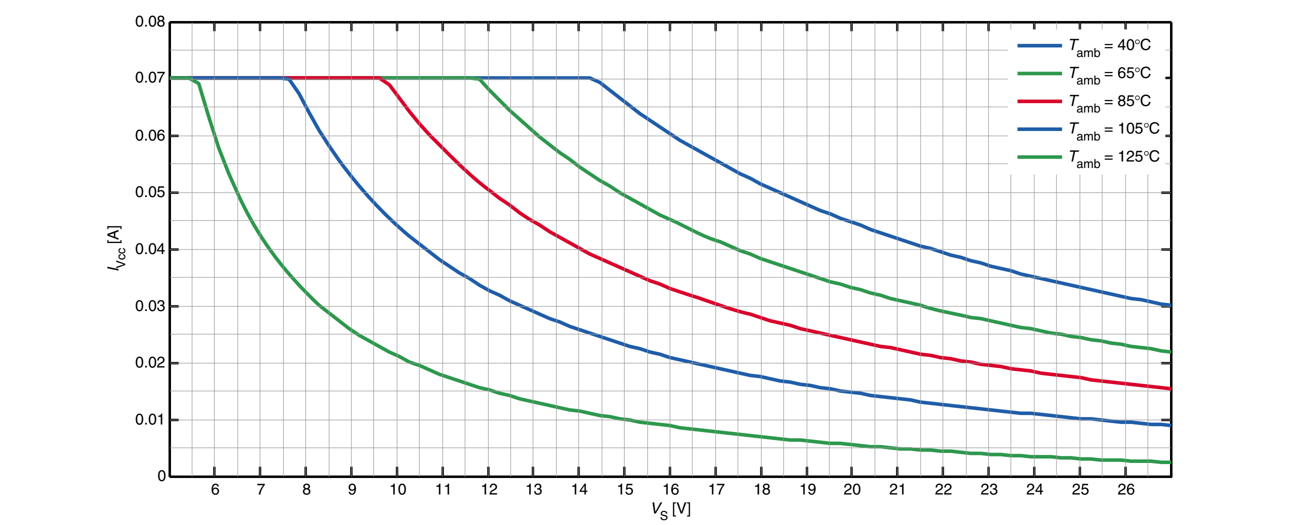


Figure 42 Safe operating area TLE8457BSJ (3.3 V LDO, PG-DSO-8 package)

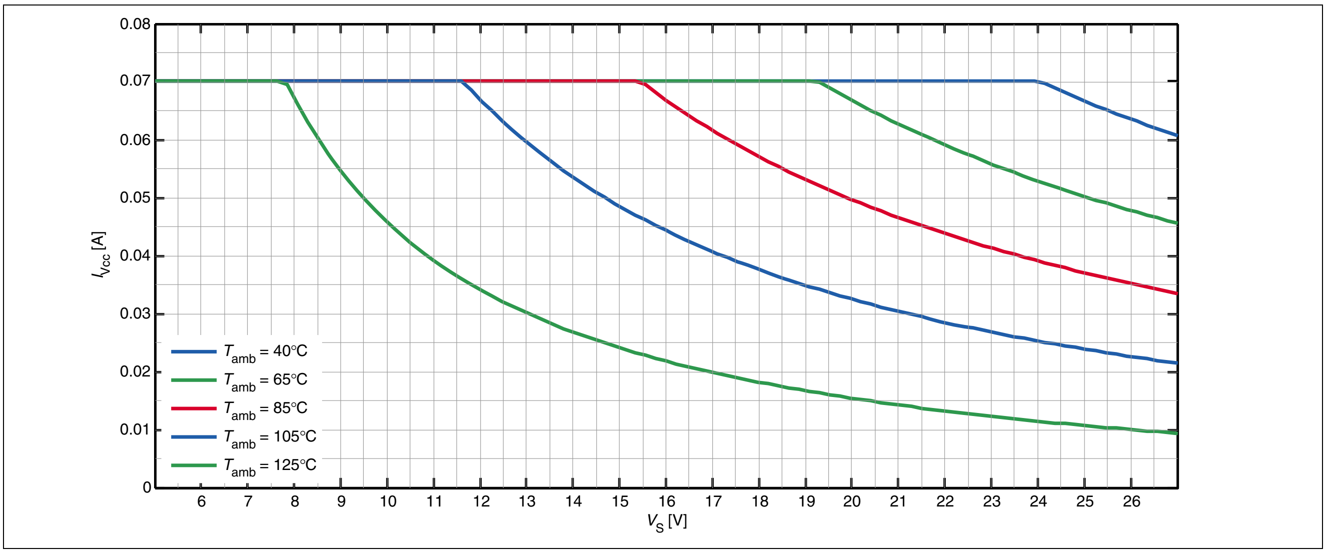


Figure 43 Safe operating area TLE8457BLE (3.3V LDO, PG-TSON-8 package)

9 EMC aspects

9.1 EME – slope control

The LIN physical layer is a single-wire, wired AND bus with a battery related recessive level. Thus smooth output wave shaping becomes more important. The Electromagnetic Emission EME mainly depends on the falling and rising slope of the LIN bus waveform. TLE8457 has optimized slope control for falling edge and rising edge in order to achieve very low Electromagnetic Emission.

For very high bit rates close to 20 bit/s the LIN bus slope times also have impact on system tolerance, such as ground shift. Thus, at higher bit rates it is not recommended to make use of the maximum capacitive load $C_{BUS, max}$ [2] allowed, in order to keep some safety margin for the system. For LIN networks with a small number of nodes C_{MASTER} can be increased to reduce EME.

9.2 EMI – capacitive load

A capacitor on the LIN bus pin reduces the impact of RF-interference. It is recommended to place a capacitor (for example $C_{MASTER/SLAVE}$ = 220 pF) from LIN to ground at each node.

10 ESD recommendations

In case of an ESD event very high current flows into the TLE8457.

A very low resistive ground wire is recommended to reduce the voltage drop in case an of ESD event. This is necessary to guarantee the excellent ESD behavior of the TLE8457. **Figure 44** shows a proposal for an ESD performance application circuit. **Figure 45** shows the critical problem in case of ESD.

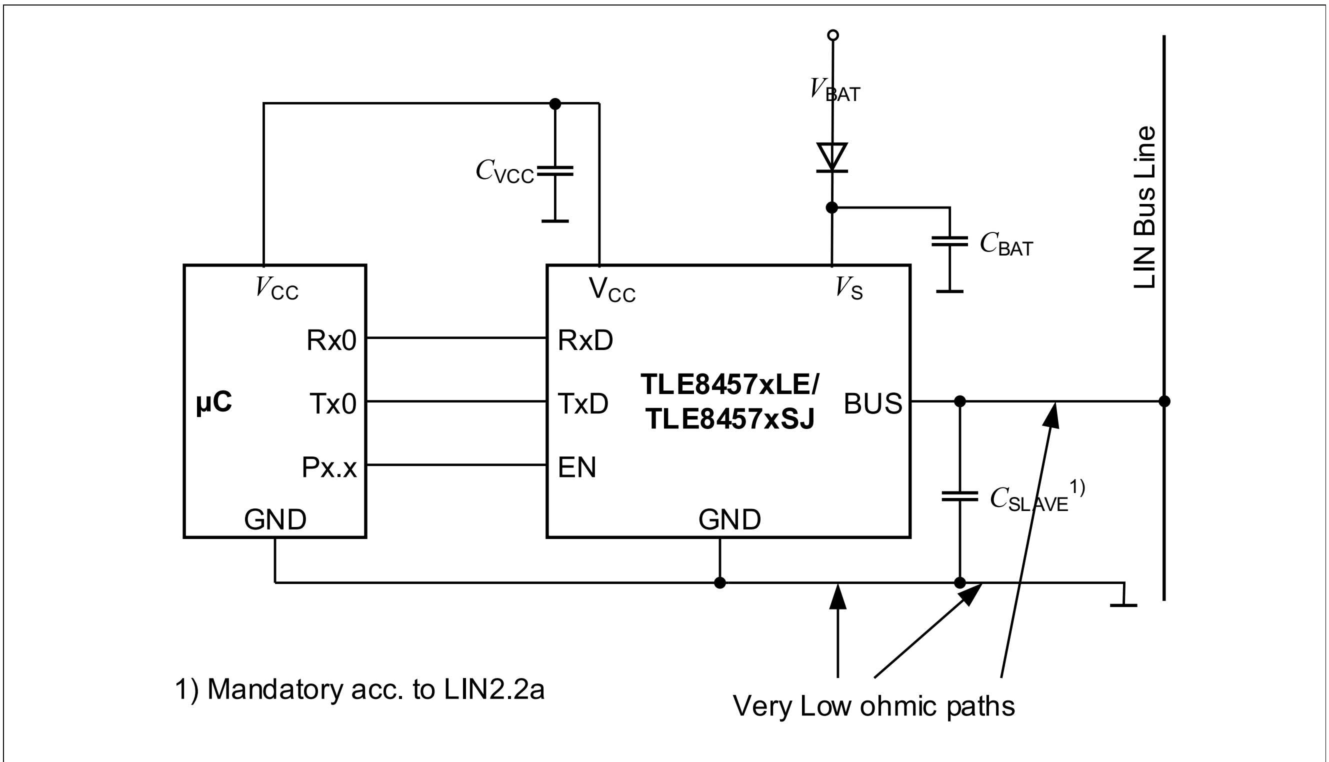


Figure 44 Proposal for an ESD Performance Application Circuit

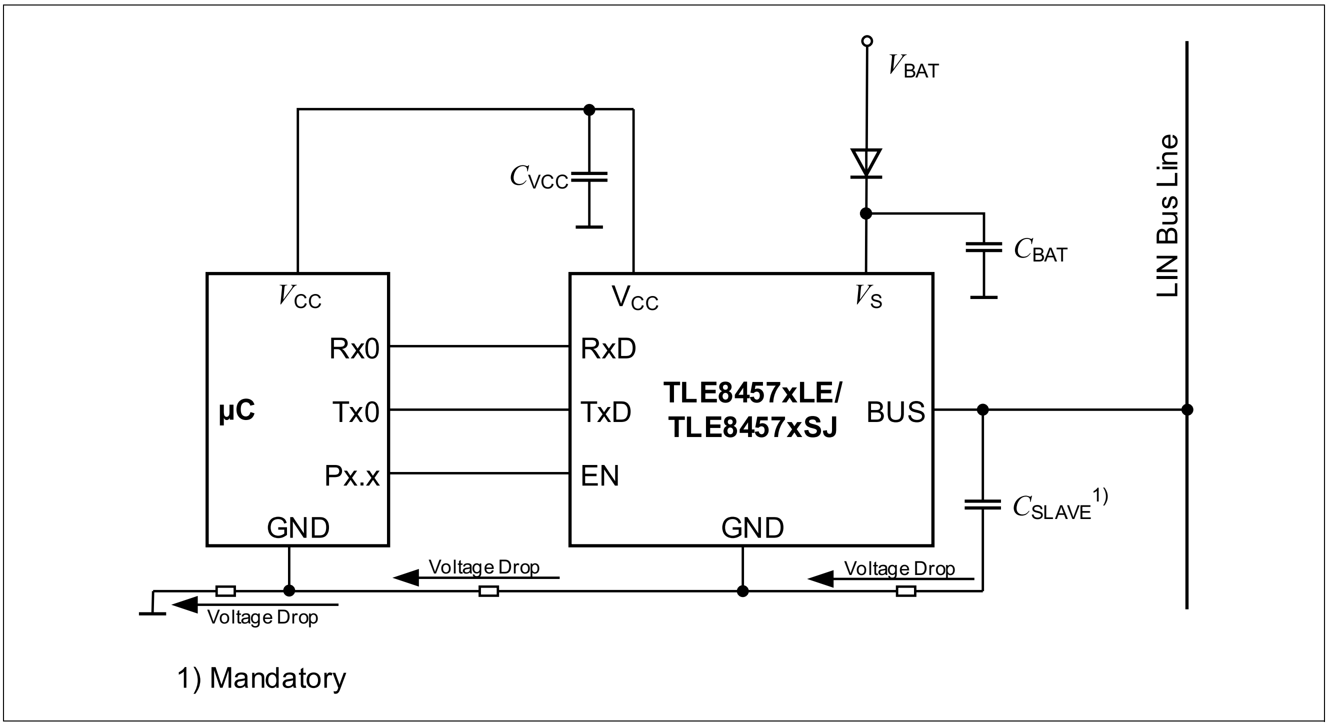


Figure 45 Critical Problem in Case of ESD

11 PCB layout recommendations

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

- keep TxD and RxD connections to microcontroller as short as possible.
- Place a 100 nF capacitor close from V_S to GND close to these pins for local decoupling. It is recommended to use a ceramic capacitor due to low ESR and low inductance.
- Do not route the LIN bus line in parallel to fast-switching lines or off-board signals in order to reduce noise injection to the LIN bus.
- It is recommended to place the master capacitor, slave capacitor and master termination resistor (only in master node) and the transceiver as close as possible together and close to the ECU connector in order to minimize track length of bus lines.
- Place the GND connector as close as possible to the transceiver in order to avoid ground shift and minimize impedance from ECU GND connector to TLE8457 GND.
- Place the stabilization capacitor close to the V_{CC} supply output pin.

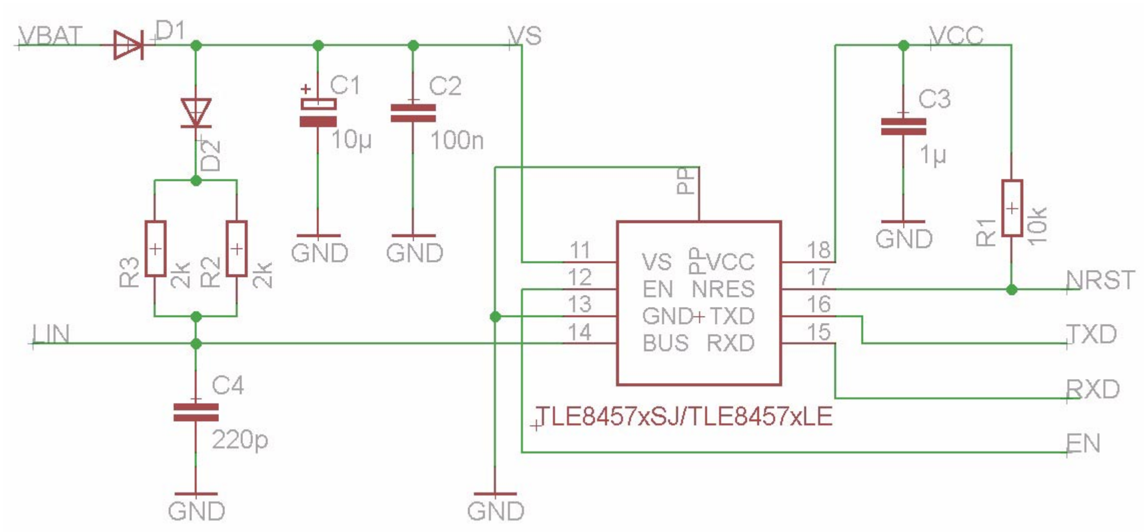


Figure 46 Example of TLE8457 schematic

- D1: Reverse polarity protection diode (mandatory according to LIN specification)
- D2, R2, R3: LIN bus master pull-up termination (required only for LIN Bus Master)
- C1, C2: V_S input stabilization capacitors (recommended)
- C3: V_{CC} output stabilization capacitor (Min. 1µF, low ESR ceramic capacitor recommended)
- C4: LIN bus capacitor (required for Master (1nF) and Slave (220 pF) applications)
- R1: Pull-up resistor for NRST pin

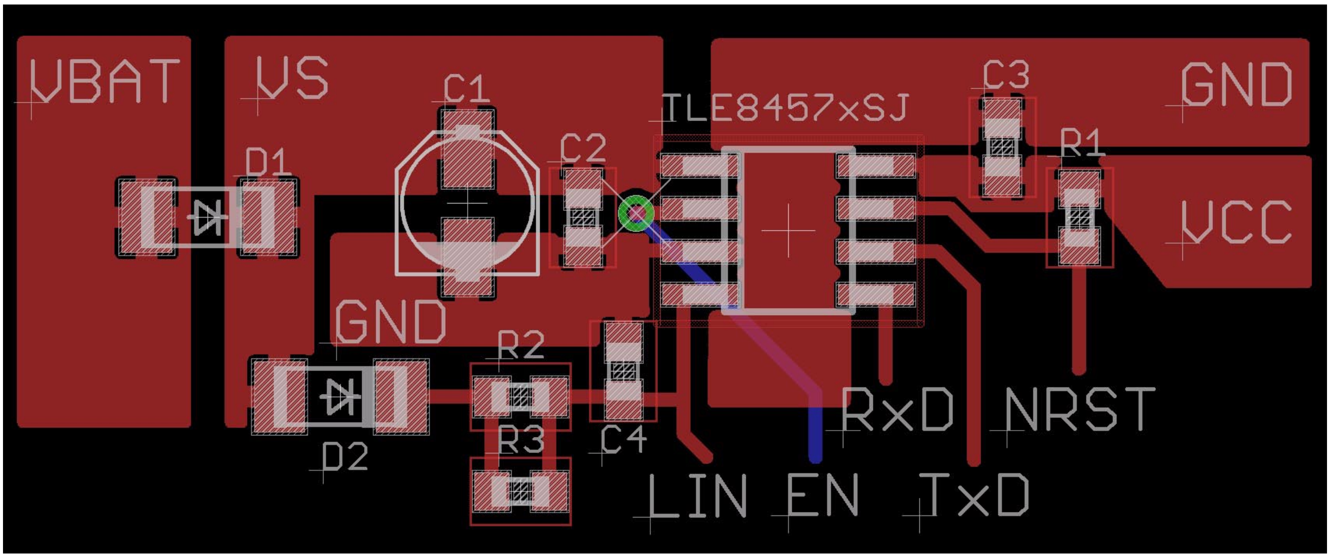


Figure 47 Example of TLE8457xSJ PCB layout

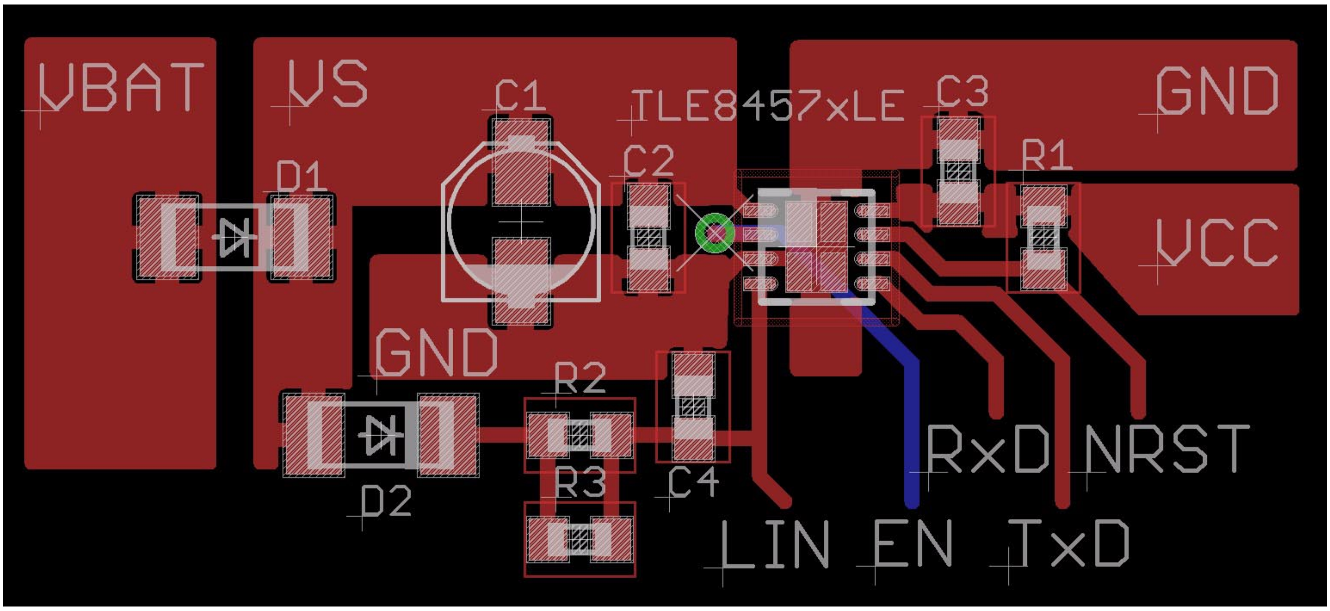


Figure 48 Example of TLE8457xLE PCB layout

12 Pin FMEA

This chapter provides a pin FMEA (Failure Mode and Effect Analysis) for typical failure situations. Typical failure scenarios for dedicated pins of TLE8457 are:

- short circuit to battery voltageV_{BAT}
- short circuit to supply voltage V_{CC}
- short circuit to PCB ground GND
- short circuit between neighboring pins
- unconnected pin

The potential failures are classified according to possible failure effects (see **Table 4**)

Table 4 Classification of failure effects

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

Table 5 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. LIN bus communication blocked for t_{TXD_TO}. If failure does not recover transmitter will stay disabled and node cannot transmit data to the LIN bus. The receiver works as specified in the datasheet.	C
TxD	Short Circuit to V_{CC}	No damage to the transceiver. Possible damage of the µC due to high voltage or high short current.	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}	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
V_{CC}	open	No damage to the transceiver.	C

Table 5 Pin FMEA overview (cont'd)

Pin	Potential Failure	Potential Effects of Failure	Class
RxD	Short Circuit to V_{CC}	RxD remains recessive.	C
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_{CC} to GND. The device gets damaged due to violation of absolute maximum ratings.	A
RxD	open	No damage to the transceiver.	C
EN	Short Circuit to V_{CC}	No damage to the transceiver. Device will enter Normal Operation Mode.	D
EN	Short Circuit to V_{BAT}	Violation of absolute maximum ratings. Device gets damaged.	A
EN	Short Circuit to GND	No damage to the transceiver. The Device will enter Stand-by Mode or Sleep Mode depending on the status of TxD.	D
EN	open	No damage to the transceiver. Due to the internal pull-up resistor the device will enter Stand-by Mode or Sleep Mode depending on the status of TxD.	
Bus (LIN)	Short Circuit to GND	No damage to the transceiver.	B
Bus (LIN)	Short Circuit to V_{BAT}	No bus communication possible. No damage to the transceiver.	B
Bus (LIN)	Short Circuit to V_{CC}	Violation of absolute maximum ratings on V_{CC}. Device gets damaged.	A
Bus (LIN)	open	No damage to the transceiver. No bus communication possible.	C
NRST	Short Circuit to GND	No damage to the transceiver. Microcontroller may stay in RESET State due to "low" signal on NRST output pin. Application will no enter Normal Mode.	D
NRST	Short Circuit to V_{BAT}	Violation of absolute maximum ratings. Device gets damaged.	A
NRST	Short Circuit to V_{CC}	No damage to the transceiver.	D
NRST	open	No damage to the transceiver.	D

Terminology

LIN	Local Interconnect Network
OEM	Original Equipment Manufacturer
SCI	Serial Communication Interface
UART	Universal Asynchronous Receiver Transmitter
EME	Electromagnetic Compatibility
EME	Electromagnetic Emission
EMI	Electromagnetic Immunity
PCB	Printed Circuit Board

13 References

[1] Data Sheet TLE8457xLE/TLE8457xSJ, LIN Transceiver, Infineon Technologies AG

[2] LIN Specification Package, LIN Protocol Specification - Revision 2.2a, LIN Consortium; ISO 17987-4

[3] International Standard ISO 9141, Road Vehicles - Diagnostic Systems - Requirement for Interchange of Digital Information, International Standardization Organization, 1989

[4] **Infineon Automotive Transceiver Homepage**

14 Revision History

Revision	Date	Changes
1.2	2017-05-05	Application Note updated: • Added **Chapter 7.2**: Jump load measurement example • Added **Chapter 7.3**: V_S ramp up measurement example
1.1	2016-12-19	Application Note updated: • Added **Chapter 5.5**: Application scenarios outside specified operating range
1.0	2016-08-25	Application Note created

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