TLE 7259G

Application Note

Automotive Power

Never stop thinking.

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Summary

This report provides application information for the transceiver TLE 7259G from Infineon Technologies AG as Physical Medium Attachment within a LIN network. It contains technical information like recommended set-ups for LIN slave and master application respectively, mode control hints and power consumption aspects.

This report refers to the data sheet of the Infineon Technologies AG LIN transceiver TLE 7259G **[1]**

1 Introduction

The Local Interconnect Network (LIN) is a low speed (max. 20 kBaud) Class-A, serial bus protocol. A LIN sub-bus is primarily intended for modules like seat, door, roof, switch panel, steering wheel, etc. Its task is to connect switches, actuators and sensors into a sub-bus that links to the main bus e.g. a CAN bus.

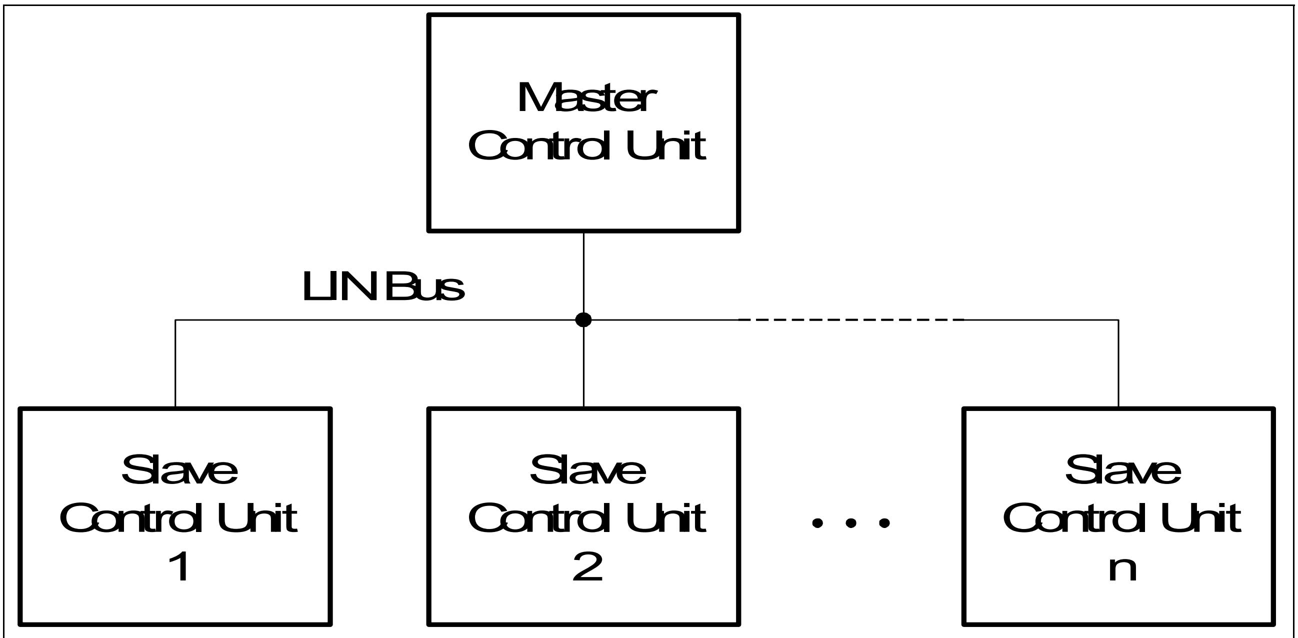


Figure 1 Single-Master / Multiple-Slave Concept

The LIN protocol [2] is based on the UART/SCI serial data link format using 8N1-coded byte fields. A LIN network consists of one master node and one or more slave nodes ; the medium access is controlled by the master node. Such a single-master/multiple-slave concept is shown in Figure 1.

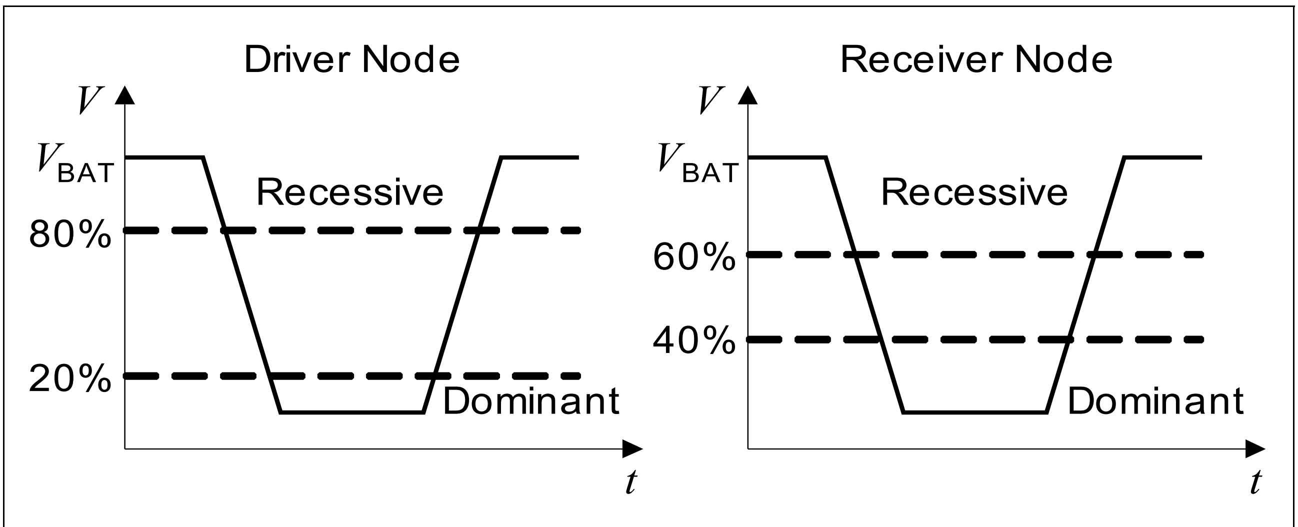


Figure 2 Voltage Levels on the LIN Bus Line

The LIN physical layer has been derived from the ISO 9141 [3] standard but has some enhancements to meet the particular operation requirements in automotive environments such as EMC, ESD, etc. The LIN bus is a single-wire, wired AND bus with a 12 V-battery related recessive level. The voltage levels on the LIN bus line are shown in Figure 2.

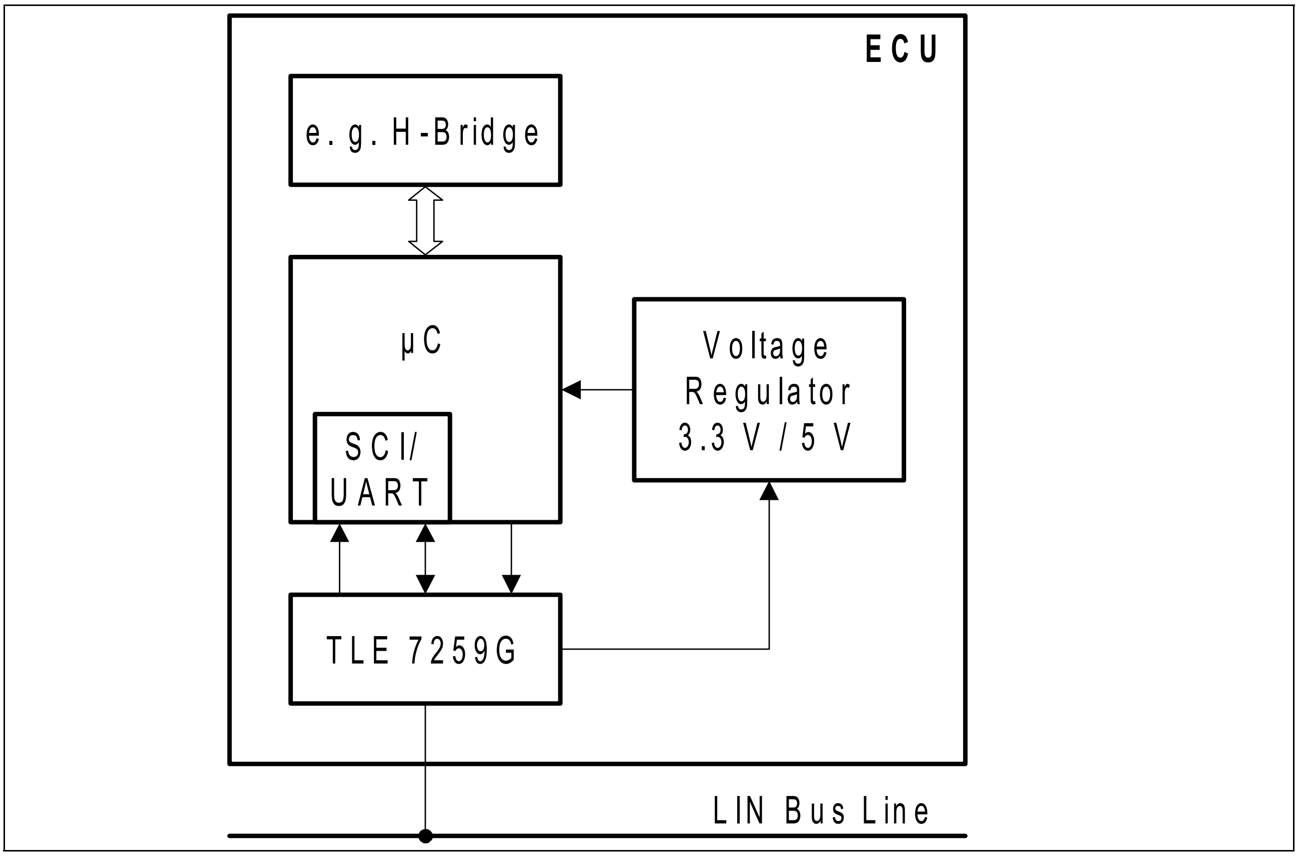


Figure 3 Typical LIN ECU

This report describes the technical implementation of the TLE 7259G [1] as Physical Medium Attachment within LIN. Its focus is to provide application hints / recommendations for the design of LIN electronic control units (ECUs) using the LIN transceiver TLE 7259G from Infineon Technologies AG (see Figure 3).

1.1 LIN norm bus termination

The LIN termination definition differentiate slaves from the master. According to the LIN norm [2], the master node should have a pull-up resistor R_{MASTER} of 1kΩ +/-10%. (including the slave termination included in the device). The slave termination resistor R_{SLAVE} should be 30kΩ typical, 20kΩ minimum, 60kΩ maximum. These resistors (slaves and master) are mandatory. A serial diode is also mandatory to avoid supply of the ECU via the LIN bus. The TLE 7259G includes the serial diode and resistor slave.

The LIN standard specify the τ of the signal from 1 to 5µs. A capacitor, from BUS line to ground is then usually needed. These capacitors help to warranty the symmetry of the signal, and to reduce the EME (see **Chapter 5**) of the system. The LIN norm requests a slave capacitor C_{SLAVE} of typical 220pF, 250pF maximum. The master capacitor C_{MASTER} should be bigger, in order to provide a 'buffer' in case of network variants with various number of nodes.

1.2 Nodes limitation of the LIN norm

The number of nodes in a LIN network should not exceed 16. Otherwise the reduced network impedance may prohibit a fault free communication under worst case conditions. Every additional node lowers the network impedance by approximately 3% (30 k || ~1 k).
The accumulated wire length in a network must be less or equal to 40 m.

1.3 Vbat- and Ground-Shift

To guarantee and excellent communication between the master and all slaves, a maximum Vbat- and Ground-Shift up to 10% from Vbat is mandatory and specified in the LIN specification **[2]**. This is a very hard requirement, because this is a limitation for the complete network and not only for an ECU. So the following recommendations should help to solve this problem in the application.

- Use a separate from the rest of the application reverse polarity diode for the LIN transceiver.
- The voltage drop on this reverse polarity diode must be smaller than 1V at -40°C
- The Vbat wire should be connected directly on the Vbat pin of the plug.
- No additional current flows in the LIN-Vbat- wire
- The ground wire is directly connected to the ground pin on the plug
- No additional current flows in the Ground wire
- The minimum Vbat voltage for Vbat- and Ground Shift is 8,87V
- The minimum Vbat voltage without Shift is 8V

2 General Description

The transceiver TLE 7259G represents the Physical Medium Attachment, interfacing the LIN master/slave protocol controller to the LIN transmission medium. The transmit data stream of the protocol controller at the TxD input is converted by the LIN transceiver into a bus signal with constant slew rate to minimize Electro Magnetic Emission (EME). The receiver of the TLE 7259G detects the data stream on the LIN bus line and transmits it via the RxD pin to the protocol controller.

The transceiver provides low-power management (see **Chapter 2.3**), consumes nearly no current in sleep mode (see **Chapter 8.1**) and minimizes the power consumption in failure modes (see **Chapter 8.2**).

The TLE 7259G transceiver is optimized for the maximum specified LIN transmission speed of 20 kBaud and is recommended for networks including up to 16 nodes **[2]**.

2.1 Features

The main features of the TLE 7259G are:

- Baud rate up to 20 kBaud
- Compatible to LIN specification 1.3 and 2.0
- High ESD robustness
- Very low ElectroMagnetic Emission (EME) due to output control slope mechanism
- High ElectroMagnetic Immunity (EMI)
- Very low current consumption in sleep mode
- Battery discharge protection in case of LIN to GND short-circuit
- Transmit data (TxD) dominant time-out function
- Wide battery supply operation range, from voltage drops (5 V) up to load dump condition(40 V)
- Suitable for 12V and 24V powernet
- Control input levels compatible with 3.3 V and 5 V devices
- Integrated termination resistor for LIN slave applications
- Local and remote wake-up in sleep mode
- Recognition of the wake-up source (local or remote)
- Fail-safe behavior in case unpowered conditions, no reverse current paths
- Bus terminal protected against short-circuits and transients in the automotive environment
- Direct battery operation with protection against load dump, jump start and transients
- No 5 V supply required
- Thermally protected

2.2 Block Diagram

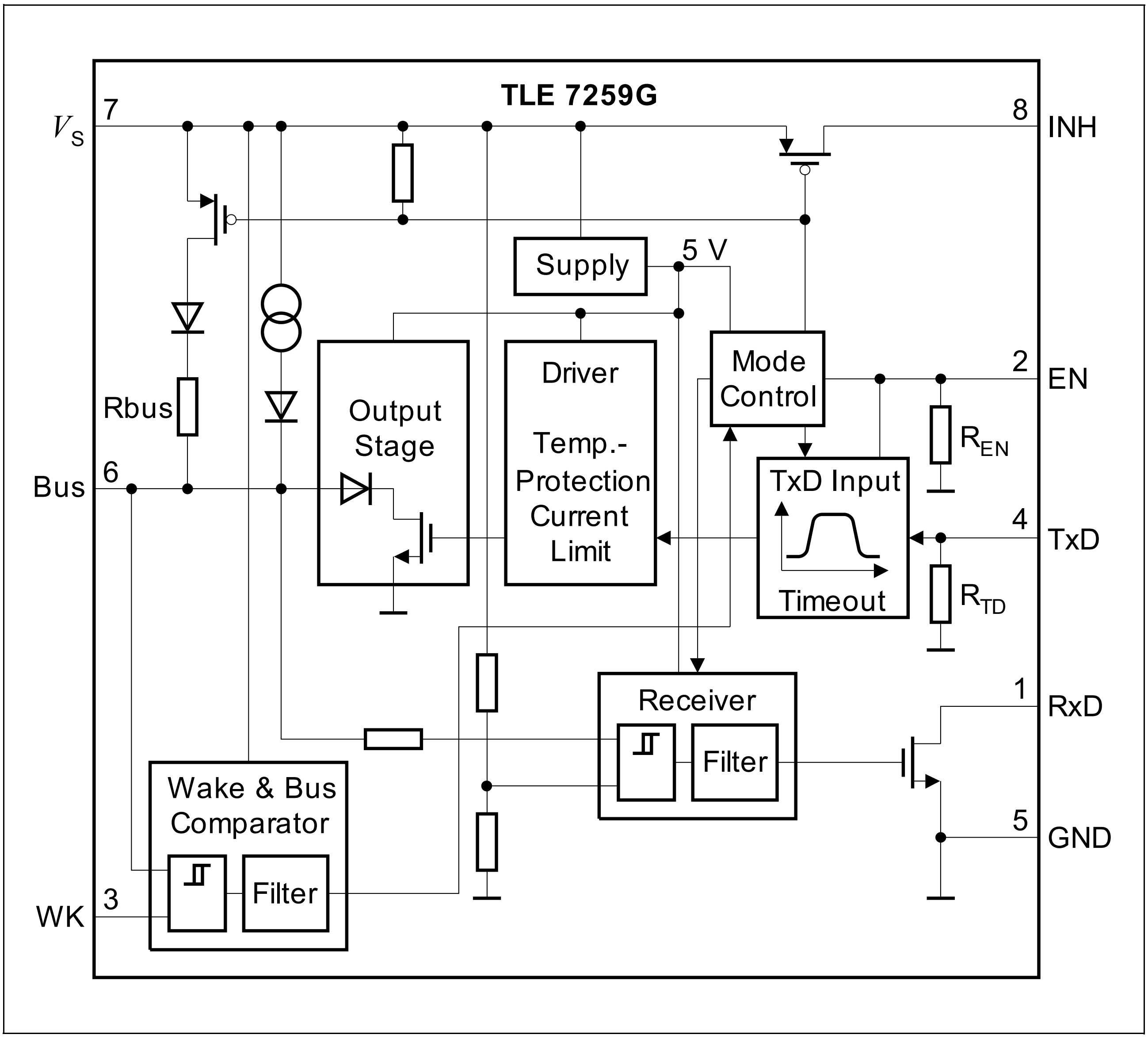


Figure 4 Block Diagram of the TLE 7259G

2.3 Operating Modes

The TLE 7259G provides three operating modes: normal slope mode, standby mode and sleep mode. The operating modes are shown in **Table 1** and **Figure 5**

Table 1 Operating Modes

Mode	EN	TxD	RxD	INH	Transmitter	R_{SLAVE}	Remarks
Sleep	0	weak pull-down	floating	floating	off	current source	see **Chapter 2.3.1**
Standby	0	weak pull-down if remote wake-up; strong pull-down if local wake-up	low	high (V_S)	off	30 kΩ typical	see **Chapter 2.3.2**
Normal Slope	1	weak pull-down	high: recessive state low: dominant state	high (V_S)	on	30 kΩ typical	see **Chapter 2.3.3**

Figure 5 shows the state diagram of the TLE 7259G.

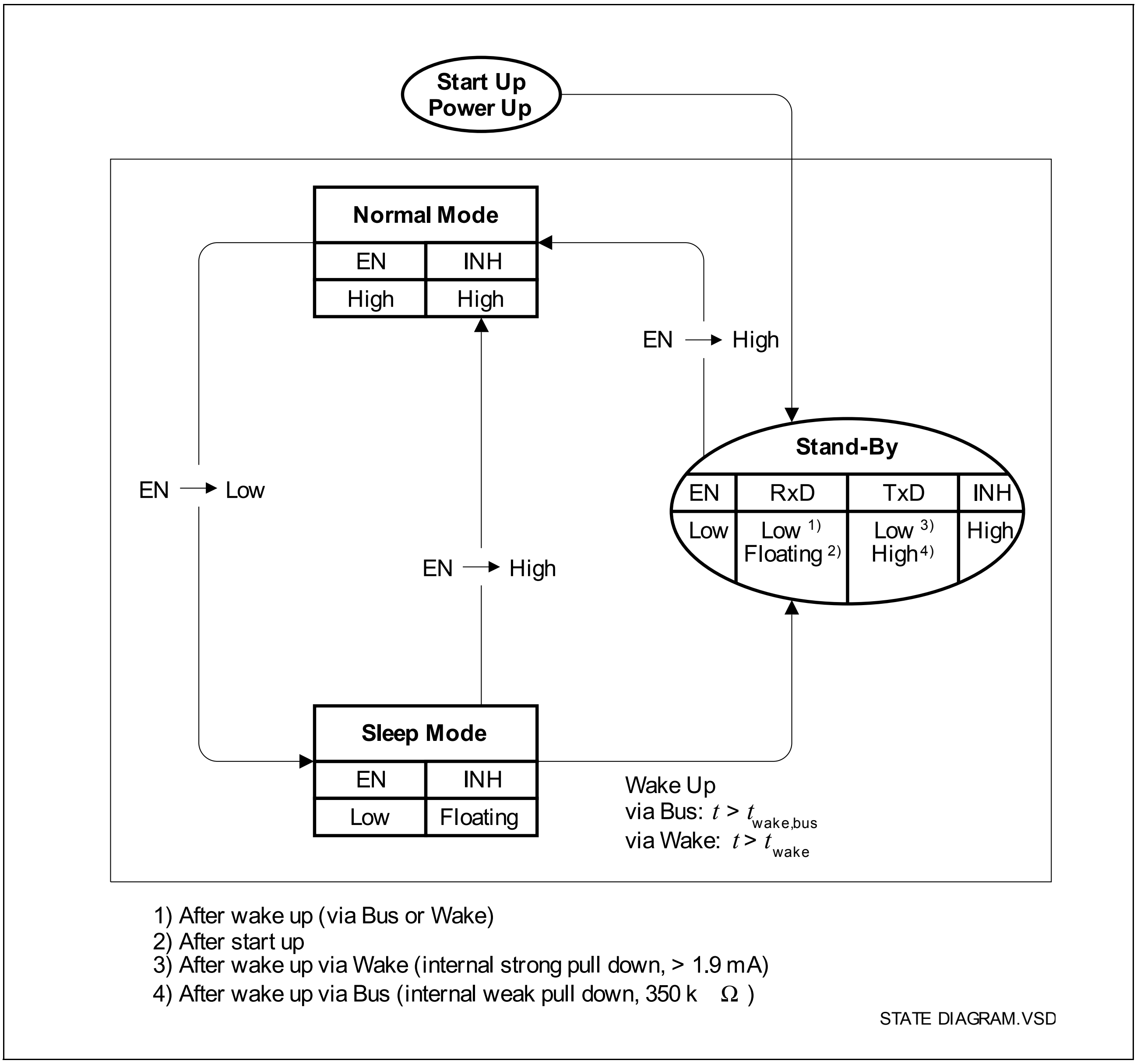


Figure 5 State Diagram

2.3.1 Sleep Mode

The sleep mode of the TLE 7259G provides the lowest achievable power consumption within LIN ECU. This is achieved by a very low current dissipation of the transceiver itself and switching off the external voltage regulator through the INH output. During sleep mode the INH output is floating.

Although the power consumption is extremely low a remote wake-up via LIN and a local wake-up via WK pin will be recognized and results in a mode change towards standby mode (see **Chapter 2.3.2**). Furthermore the TLE 7259G provides a direct activation to normal mode via EN (see **Chapter 2.3.3**) which is useful for applications where the micro controller supply is not controlled by the INH output.

The TLE 7259G 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 (LIN), of the local wake-up input (WK) and of the sleep control input (EN). Therefore all wake-up events have to maintain for a certain time period (t_{WK}, $t_{WK, BUS}$, t_{snorm}).

The sleep mode is entered if a low level at the sleep control input pin EN maintains for at least t_{nsleep} **[1]** (see **Figure 6**) and no wake-up event (remote or local) happens within this time. This filter time prevents unintended transitions towards sleep mode caused by EMI. The activation of the sleep mode is even possible if LIN and/or WK are clamped to ground, e.g. caused by a short-circuit to ground.

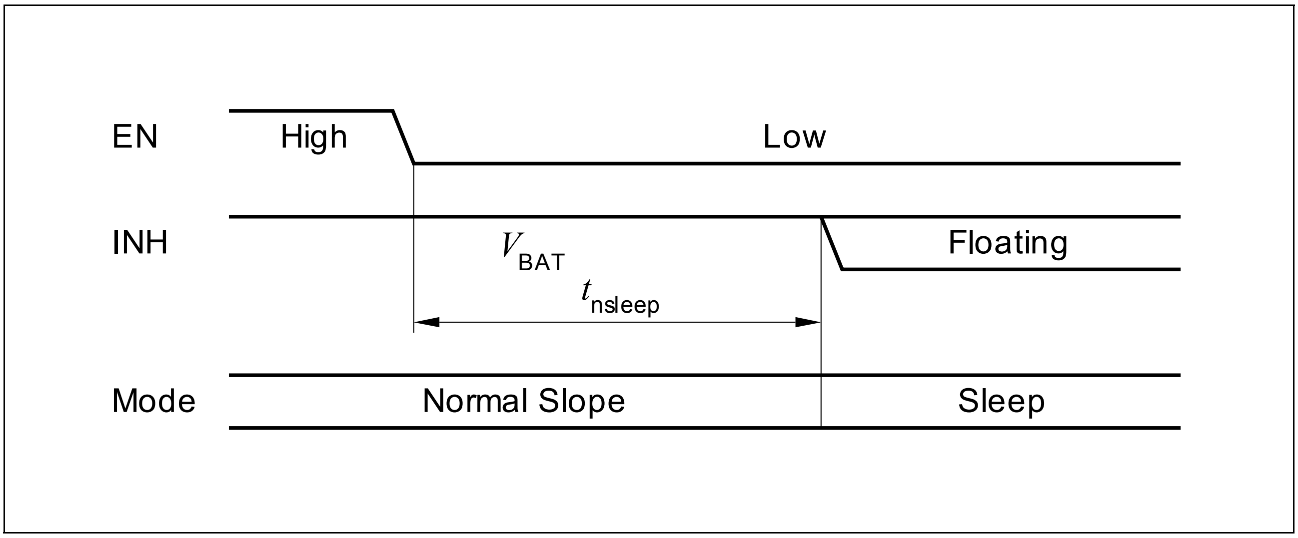


Figure 6 Sleep Mode Timing

During sleep mode, the internal slave termination resistor R_{BUS} between LIN and BAT is disabled; only a weak current source is present. This minimizes the current consumption in case LIN bus is short-circuited to ground.

2.3.2 Standby Mode

The standby mode is an intermediate mode that is entered only if a remote or local wake-up occurs while the TLE 7259G is in its sleep mode. In standby mode the INH pin outputs a battery related high level and therefore can activate an external voltage regulator. In addition the internal slave termination resistor R_{BUS} between LIN and BAT is activated.

The TLE 7259G signals the standby mode with a low level at the RxD pin. This can be used as wake-up interrupt request for a micro controller. Furthermore the wake-up source is signalled by the pull-down condition at the TxD pin. A remote wake-up event results in a weak pull-down and a local wake-up event results in a strong pull-down at

TxD. Depending on the used micro controller an external pull-up resistor could be necessary (see **Chapter 3.2.2**).

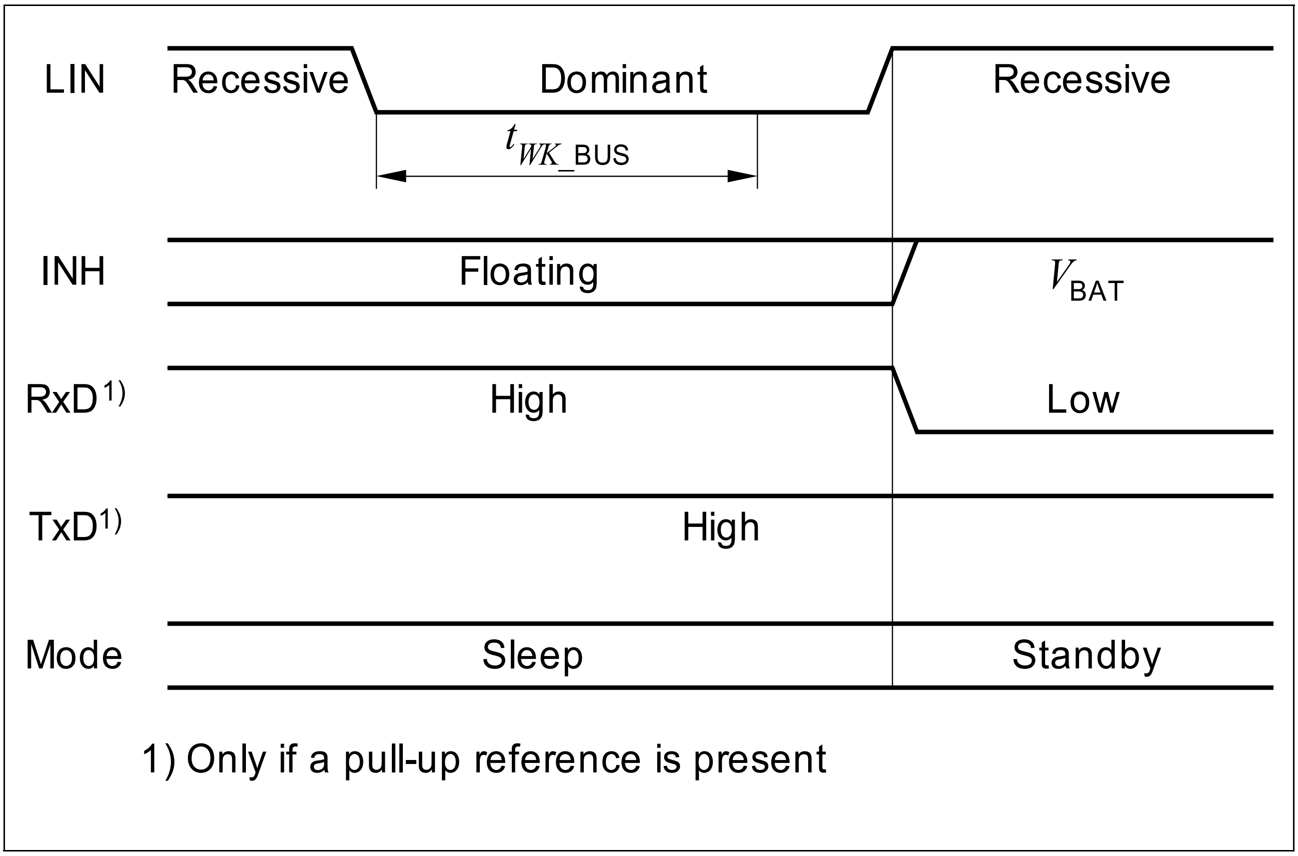


Figure 7 Standby Mode Timing of Remote Wake-up

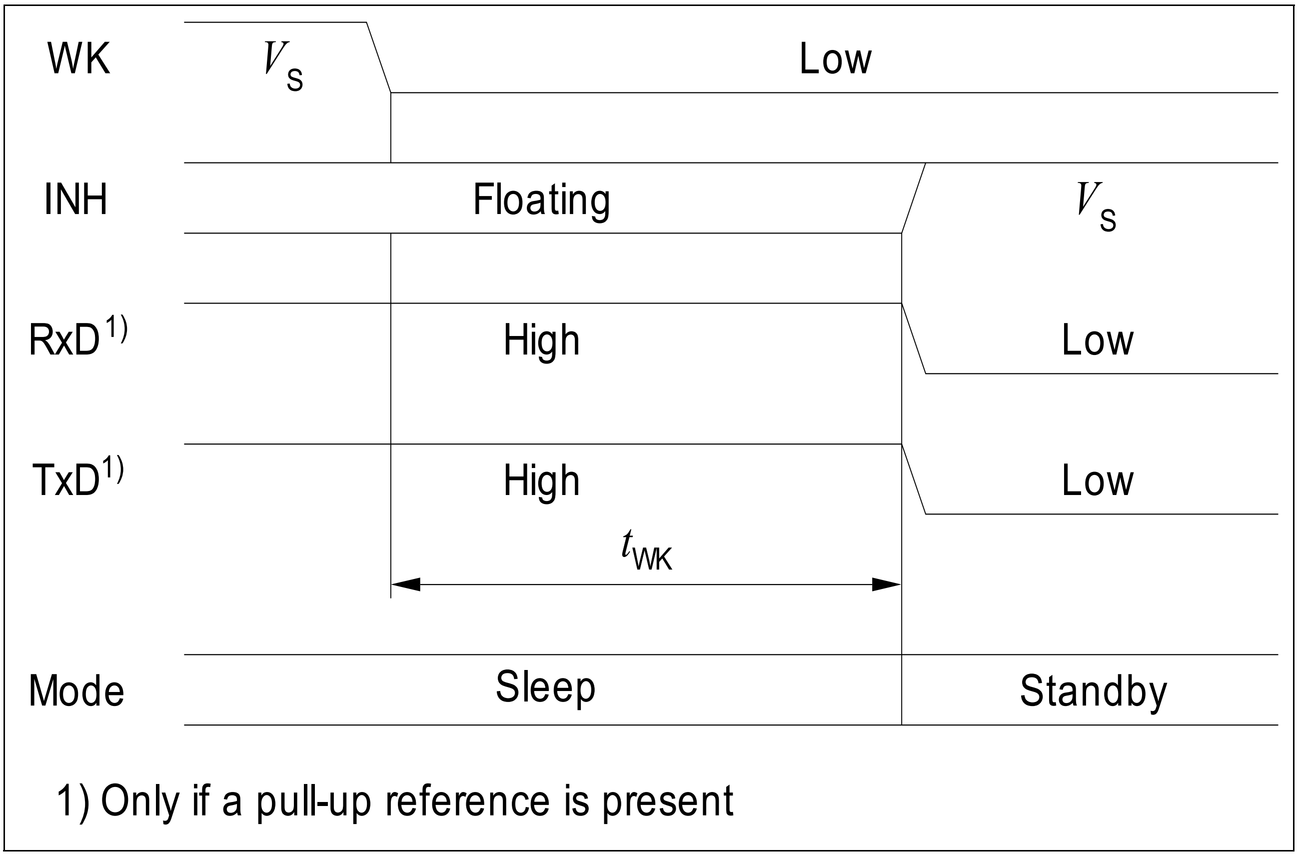


Figure 8 Standby Mode Timing of Local Wake-up

Figure 7 and **Figure 8** show the timing of a remote and local wake-up and their particular outputs at RxD and TxD. A remote wake-up via LIN bus is detected, if the LIN wire becomes continuously dominant for at least t_{WK_BUS} **[1]** followed by an edge to recessive bus level. A falling edge at the WK pin results in a local wake-up if the low level maintains for at least t_{WK} **[1]**.

2.3.3 Normal Mode

The normal mode is used to transmit and receive data via the LIN bus line. The bus data stream is converted by the receiver into a digital bit stream and output at the RxD to the micro controller. A high level on the RxD pin represents a recessive level on the LIN bus line and a low level on the RxD pin represents a dominant LIN bus line. The transmitter of the TLE 7259G converts the data stream of the micro controller at the TxD input into a wave shaped LIN bus signal to minimize the EME. A low level TxD input results in a dominant LIN bus level while a high level input results in a recessive bus level.

In normal mode the internal slave termination resistor R_{BUS} **[1]** pulls the LIN bus pin high. The INH pin provides a battery related high level to keep an external voltage regulator on.

The normal mode is entered setting EN and TxD high for at least $t_{snorm, max}$ [1]. The mode transition is executed when t_{snorm} [1] is expired. Figure 9 shows the timing of a transition from sleep or standby mode to normal slope mode.

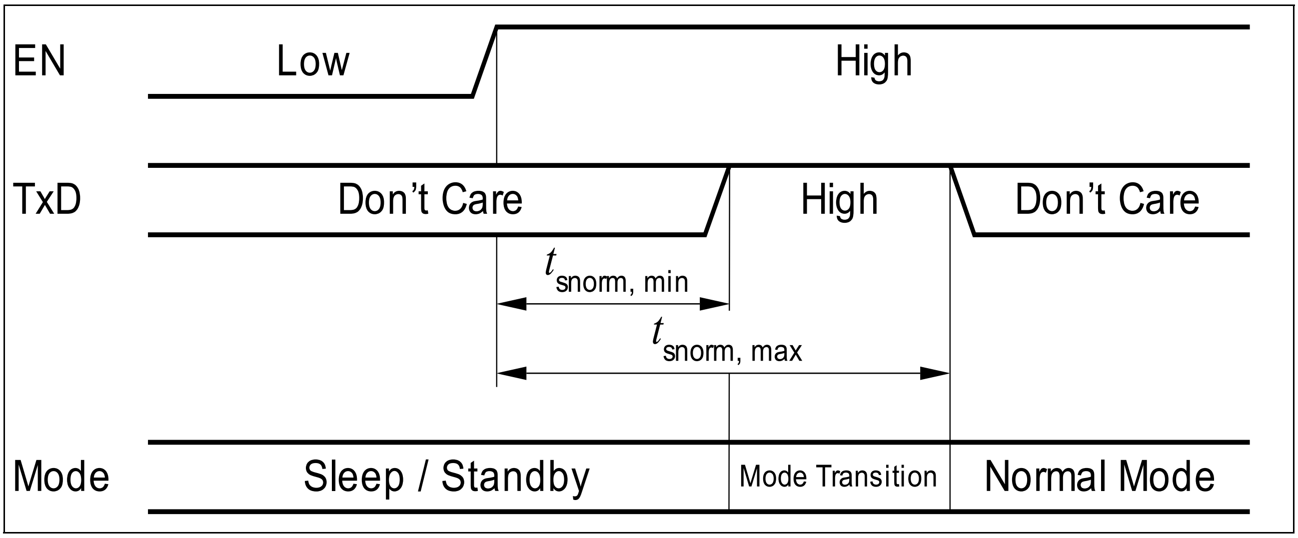


Figure 9 Normal Mode Timing

2.4 Compatibility with 3.3 V Devices

The TLE 7259G is designed to support the increasing demand for lower supply voltages than 5 V within automotive applications. It provides reduced input thresholds at the input pins TxD and EN and open drains at the output pins RxD and TxD. So it is compatible to 3.3 V supplied micro controller as well as to 5 V supplied devices. There is no 5 V tolerant behavior of interface pins between the TLE 7259G and the host micro controller needed and furthermore no extra V_{CC} supply for the transceiver itself required.

To achieve a suitable high level at RxD and TxD an external pull-up resistor might be required in case such a pull-up resistor is not part of the micro controller port pin itself.

2.5 Typical bus signal

During normal communication on the bus, the switch controls the slope of the LIN signal. A comparator measures the voltage on the bus and understand the signal as recessive or dominant. The RxD pin of the transmitter is also moving with the bus, allowing the transmitter to read the transmitted message and possibly diagnose failures (see Chapter 7). To warranty the synchronization of the receivers, it is important to enforce a certain symmetry and duty cycle of the signal. The Figure 10 shows the typical bus signal, from TxD to RxD to describes the parameters D1 and D2 [1].

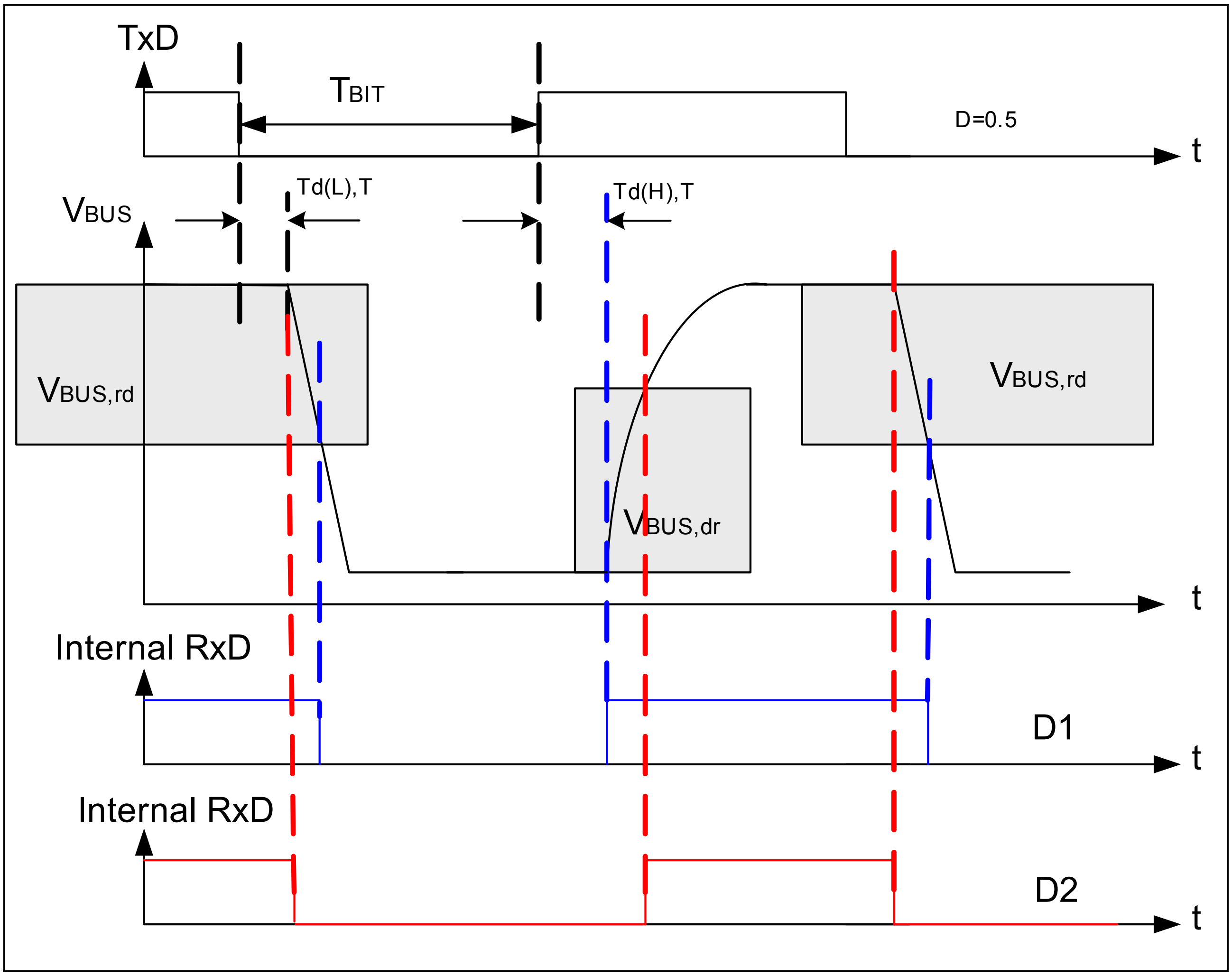


Figure 10 **Relation between propagation delay and duty cycle**

3 Slave Application

3.1 Set-up

A slave application of the LIN transceiver TLE 7259G is shown in **Figure 11**. The protocol controller (e.g. micro controller) is connected to the LIN transceiver via a UART/SCI based interface or standard I/O port pins. The TxD pin of the TLE 7259G is the transmit data input and the RxD pin is the receive data output. The sleep control input EN of the LIN transceiver can be controlled by a micro controller port pin. The TLE 7259G provides an internal slave termination resistor. Thus for a slave application no extra LIN bus termination resistor is needed. The capacitor C_{SLAVE} in **Figure 11** is recommended in order to improve the EME as well as EMI performance of the LIN system (see also **Chapter 5**).

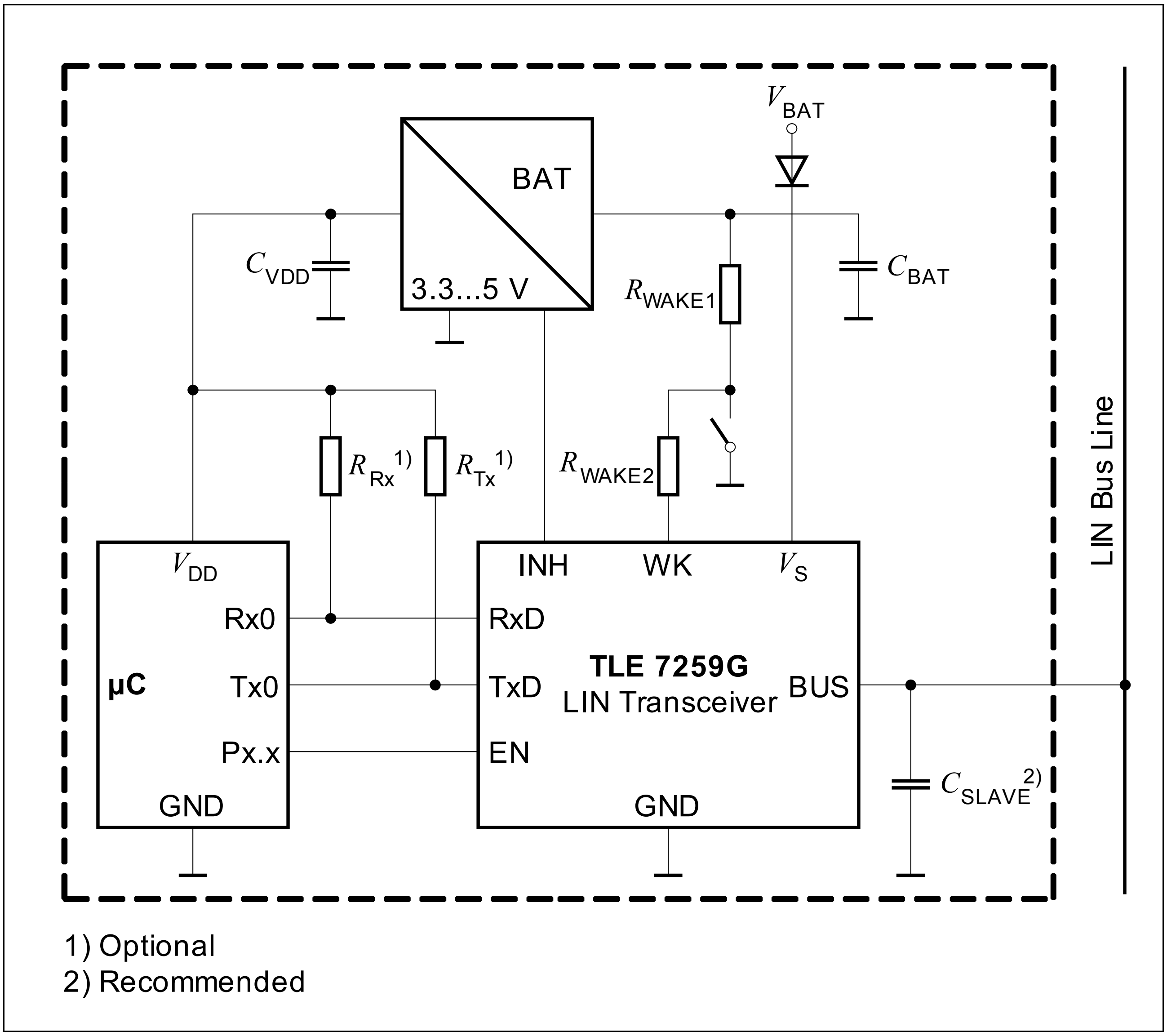


Figure 11 TLE 7259G Application Example as slave node

3.2 Detailed Pin Description

3.2.1 EN Pin

The sleep control pin EN provides an internal pull-down resistor R_{EN} to support a defined input level in case of open circuit failures. A low level results in the sleep mode and reduces the power consumption to a minimum. The range of the input threshold is chosen to support 5 V as well as 3.3 V supplied devices. A typical EN pin application is shown in **Figure 12**.

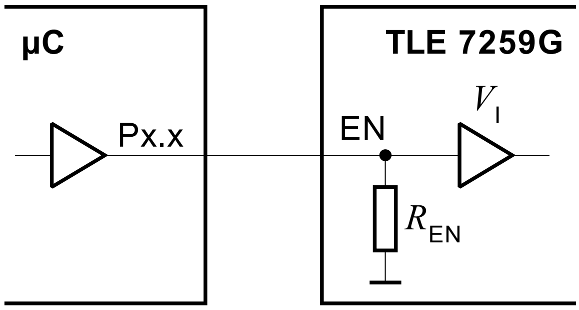


Figure 12 Typical EN Pin Application

The minimum drive capability of the micro controller port pin for the EN pin can be calculated with the following equation:

Min. high level port pin strength @ $V_{\mu C} > V_{EN,\ ON\ max}$:

$$I_{HIGH(\mu C),\ min} = \frac{V_{EN,\ ON\ max}}{R_{EN,\ min}} + I_{EN,\ hc\ max}$$

with [1]

$V_{EN\ ON\ max}$	maximum EN HIGH-level input voltage threshold
$R_{EN,\ min}$	minimum EN pull-down resistor
$I_{EN,\ hc\ max}$	maximum EN LOW-level input current

3.2.2 TxD Pin

3.2.2.1 Wake-up Source Recognition

The TxD pin is a bi-directional pin. In normal mode it is used as transmit data input whereas in standby mode the wake-up source is signalled. Here an active low output of the TxD pin indicates a local wake-up event on the WK pin. If a local wake-up source at the WK pin is used, a pull-up behavior at pin TxD is required. This pull-up can be achieved in two ways:

a) The micro controller port pin provides an integrated pull-up $R_{Tx(\mu C)}$ (see **Figure 13a**).
b) An external pull-up resistor $R_{Tx(ext)}$ towards the local V_{CC} is connected (see **Figure 13b**).

In case no local wake-up source is present (WK is unused), no external pull-up resistor is required. Then TxD will never be pulled to a strong low level by the TLE 7259G.

If the local wake-up feature of the TLE 7259G is used, the required pull-up strength of the external pull-up R_{Tx} is defined by

a) The drive capability of the integrated wake-up source transistor pulling TxD to low in case of a local wake-up event and
b) The integrated TxD pull-down resistor R_{TxD} [1] of the TLE 7259G.

The required strength of the micro controller port pin as well as the value of the pull-up resistor R_{Tx} can be calculated by the following equations:

Min. high level pull-up current @ $V_{Tx(\mu C)} > V_{IH(TxD),\,min}$:

$$I_{HIGH(RTx),\,min} = \frac{V_{IH(TxD),\,min}}{R_{TxD,\,min}} + I_{IL(TxD),\,max}$$

Max. low level pull-up current @ $V_{Tx(\mu C)} < V_{IL(TxD),\,max}$:

$$I_{LOW(RTx),\,max} = \frac{V_{IL(TxD),\,max}}{V_{TxD}} \times I_{OL(TxD),\,min}$$ with $V_{TxD} = 0.4\ \mathrm{V}$

Range of pull-up resistor:

$R_{Tx,\,min} < R_{Tx} < R_{Tx,\,max}$ with

$$R_{Tx,\,min} = \frac{V_{CC,\,max} - V_{IL(TxD),\,max}}{I_{LOW(RTx),\,max}} \quad \text{and} \quad R_{Tx,\,max} = \frac{V_{CC,\,min} - V_{IH(TxD),\,min}}{I_{HIGH(RTx),\,min}}$$

with [1]

$V_{IH(TxD),\,min}$	minimum TxD HIGH-level input voltage
$V_{IL(TxD),\,max}$	maximum TxD LOW-level input voltage
$R_{TxD,\,min}$	minimum TxD pull-down resistor
$I_{IL(TxD),\,max}$	maximum TxD LOW-level input current
$I_{OL(TxD),\,min}$	minimum TxD LOW-level output current

Note: For LIN the signal symmetry of the falling and rising transition on TxD has an impact on the overall system tolerances. Thus it is recommended to keep the RC-load time constant on the TxD input as small as possible.

Example: If the supply voltage of the micro controller ($V_{CC} = V_{CC,\,min} = V_{CC,\,max}$) is 5 V, then the range of the pull-up resistor R_{Tx} is:

$$R_{Tx,\,min} = \frac{V_{CC,\,max} - V_{IL(TxD),\,max}}{I_{LOW(RTx),\,max}} = 1.4\ \mathrm{k\Omega}$$ with

$$I_{\text{LOW(RTx), max}} = \frac{V_{\text{IL(TxD), max}}}{V_{\text{TxD}}} \times I_{\text{OL(TxD), min}} = 3\ \text{mA}$$

$$R_{\text{Tx, max}} = \frac{V_{\text{CC, min}} - V_{\text{IH(TxD), min}}}{I_{\text{HIGH(RTx), min}}} \approx 140\ \text{k}\Omega \qquad \text{with}$$

$$I_{\text{HIGH(RTx), min}} = \frac{V_{\text{IH(TxD), min}}}{R_{\text{TxD, min}}} + I_{\text{IL(TxD), max}} = 21\ \mu\text{A}$$

A recommended value for the pull-up resistor R_{Tx} is 2.2 kΩ.

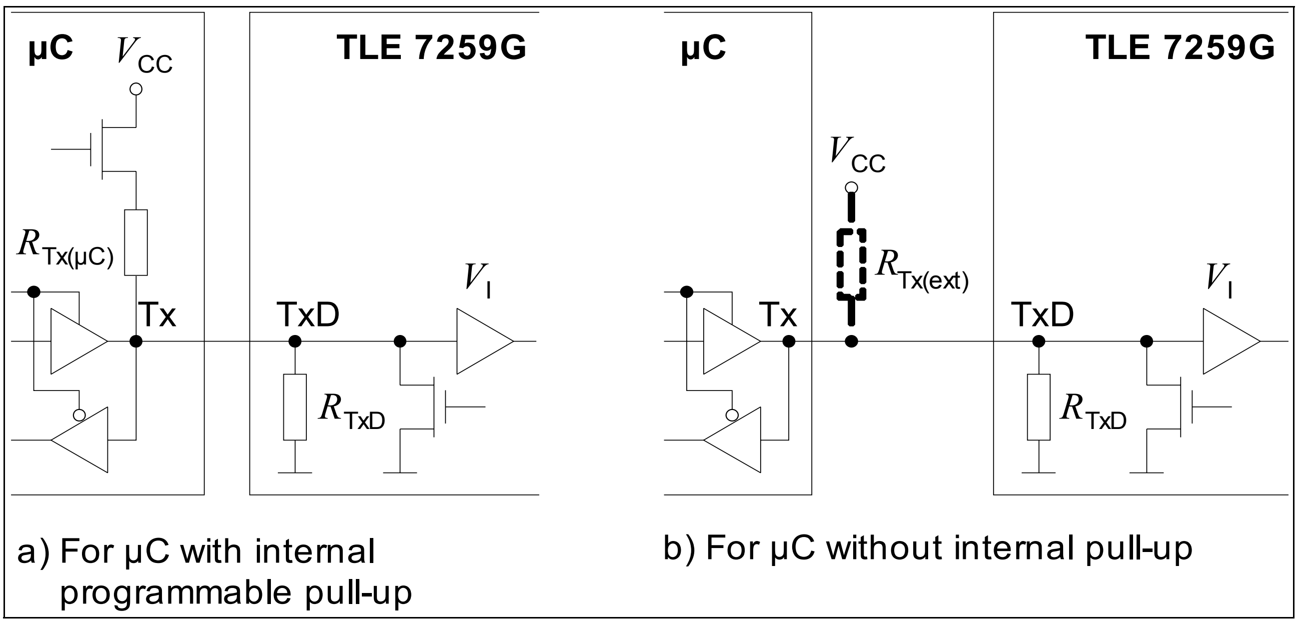


Figure 13 Typical TxD Pin Application

The open drain output as well as the maximum value of the input threshold $V_{IH(TxD)}$ [1] are designed to support 3.3 V as well as 5 V micro controller derivatives. Thus 3.3 V micro controller derivatives without 5 V tolerant ports can be used for the TLE 7259G.

3.2.2.2 Open Circuit Handling

The TxD pin provides an internal weak pull-down resistor R_{TxD} [1] to ensure a defined input level in case of open circuit failures. Although this TxD input level is dominant, the TxD dominant time-out function prevents the LIN bus from being clamped to a dominant level by disabling the transmitter. Furthermore the weak pull-down allows providing an output level free TxD pin.

3.2.3 RxD Pin

The receive data output RxD provides an open drain behavior in order to get an output level, which can be adapted to the micro controller supply voltage. Thus 3.3 V micro controller derivatives without 5 V tolerant ports can be used. In case the micro controller port pin does not provide an integrated pull-up, an external pull-up resistor connected to the micro controller supply voltage V_{CC} is required. In **Figure 14** typical RxD applications are shown.

The pull-up resistor R_{Rx} is defined by the drive capability of the TLE 7259G RxD output pin and can be calculated by the equations below:

Range of pull-up resistor:

$R_{Rx,\,min} < R_{Rx} < R_{Rx,\,max}$ with

$$R_{Rx,\,min} = \frac{V_{CC,\,max} - V_{LOW(Rx),\,max}}{V_{LOW(Rx),\,max}} \times \frac{V_{RxD}}{I_{OL(RxD),\,min}}, \qquad V_{RxD} = 0.4\text{ V} \qquad \text{and}$$

$$R_{Rx,\,max} = \frac{V_{CC,\,min} - V_{HIGH(Rx),\,min}}{I_{LH(RxD),\,max}}$$

with

$I_{LH(RxD),\,max}$	maximum RxD HIGH-level leakage current [1]
$I_{OL(RxD),\,min}$	minimum RxD LOW-level output current [1]
$V_{HIGH(Rx),\,min}$	minimum µC port pin (Rx) HIGH-level input voltage
$V_{LOW(Rx),\,max}$	maximum µC port pin (Rx) LOW-level input voltage

Note: For LIN the signal symmetry of the falling and rising transition on RxD has an impact on the overall system tolerances. Thus it is recommended to keep the RC-load time constant on the RxD output as small as possible, but the pull-up resistor R_{Rx} should not be below 1 kΩ.

Example: If the supply voltage of the micro controller ($V_{CC} = V_{CC,\,min} = V_{CC,\,max}$) is 5 V and the minimum micro controller port input threshold voltage range is from $V_{LOW(Rx),\,max} = 0.8$ V to $V_{HIGH(Rx),\,min} = 2$ V, then the range of the pull-up resistor R_{Rx} is:

$$R_{Rx,\,min} = \frac{V_{CC,\,max} - V_{LOW(Rx),\,max}}{V_{LOW(Rx),\,max}} \times \frac{V_{RxD}}{I_{OL(RxD),\,min}} = 1.4\text{ k}\Omega$$

$$R_{Rx,\,max} = \frac{V_{CC,\,min} - V_{HIGH(Rx),\,min}}{I_{LH(RxD),\,max}} \approx 600\text{ k}\Omega$$

A recommended value for the pull-up resistor R_{Rx} is 2.2 kΩ

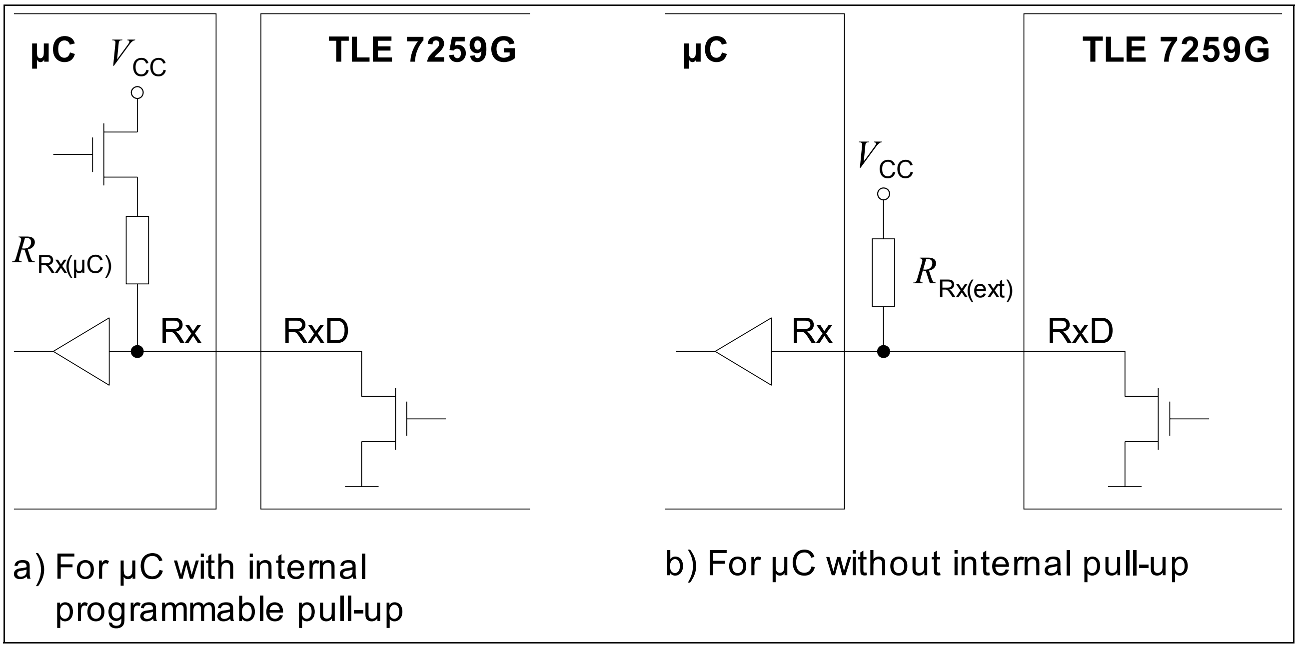


Figure 14 Typical RxD Pin Application

3.2.4 WK Pin

The local wake-up input WK is used to detect local wake-up events using a falling edge. This falling edge has to be followed by a continuous low level of at least t_{WK} in order to guarantee an optimum EMI filtering behavior. The WK pin provides an internal weak pull-up current source I_{WK_PU}[1] towards battery, which defines a high pin level in case of open circuit failures. It is recommended to connect an external pull-up resistor R_{WAKE1} to provide sufficient current for an external wake-up switch or transistor. In case the wake-up source (switch or transistor) at WK has a different ground path than the TLE 7259G, it is recommended to add a series resistor R_{WAKE2} between the WK pin and the wake-up source. If the ECU has lost its ground while the wake-up source is still connected to ground, the serial resistor R_{WAKE2} protects the ECU against a reverse current supply through the internal protection diodes of WK. Figure 15a shows a typical WK pin application for local wake-up via external switch.

The pull-up resistor R_{WAKE1} depends only on the required current of the wake-up source (switch or transistor), whereas the series resistor R_{WAKE2} is mainly defined by the applications ground shift between the ECU and the external wake-up source. The following equations show how to calculate the recommended series resistor:

Range of series resistor:

$R_{WAKE2,\ min} < R_{WAKE2} < R_{WAKE2,\ max}$ with

$$R_{WAKE2,\ min} = \frac{V_{BAT,\ max}}{I_{WK,\ min}}$$ and

$$R_{WAKE2,\ max} = \frac{V_{WK,\ L,\ max} - |V_{GND\text{-}shift}|}{I_{WKPU}}$$ with e.g. $V_{GND\text{-}shift}$ = 1.5 V

with [1]

$V_{WK,\ Lx}$	maximum WK LOW-level input voltage
$I_{WK\ PU}$	minimum WK pull-up current
$I_{WK,\ min}$	minimum WK output current (limiting value)

Example: For a maximum ground-shift of $V_{GND\text{-}shift}$ = 1.5 V and a battery voltage range of V_{BAT} = 5...27 V is the range of R_{WAKE2}:

$$R_{WAKE2,\ min} = \frac{V_{BAT,\ max}}{I_{WK,\ min}} = 1.8\ \text{k}\Omega$$

$$R_{WAKE2,\ max} = \frac{V_{IL(WK),\ max} - |V_{GND\text{-}shift}|}{I_{IL(WK),\ min}} \approx 6.6\ \text{k}\Omega$$

Therefore a typical value for the series resistor R_{WAKE2} is 3 kΩ.

If no local wake-up is required for the application the WK pin can be left open, due to the internal pull-up and filter behavior. Nevertheless it is recommended to connect the WK pin directly to the BAT pin (see **Figure 15b**) if not used.

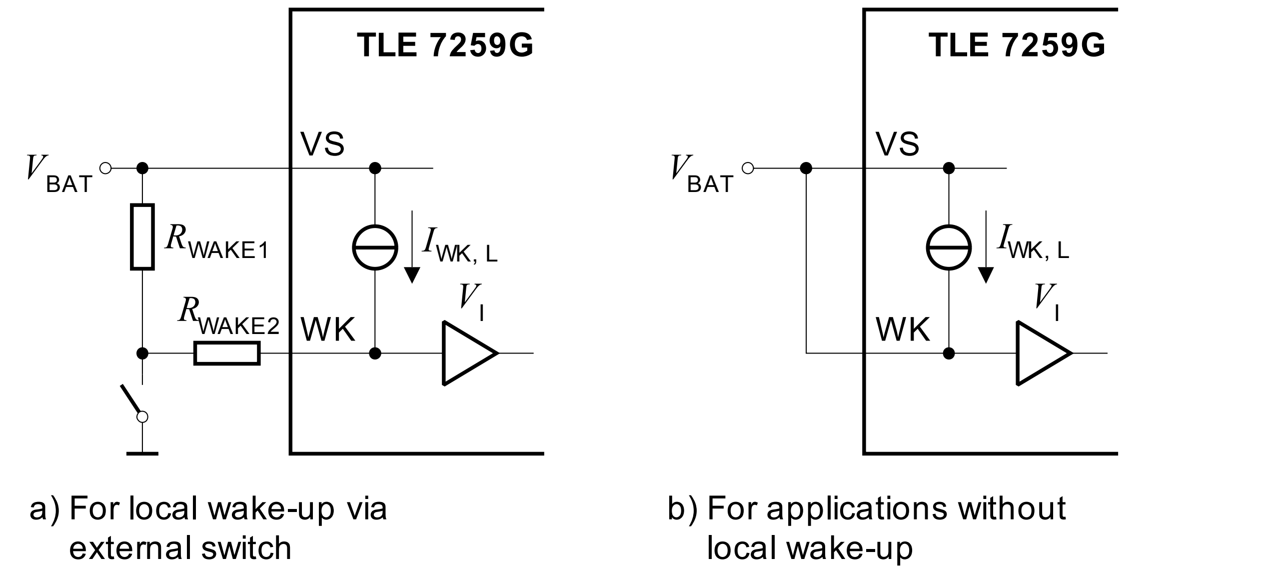


Figure 15 Typical WK Pin Application

The TLE 7259G provides also hardware compatibility to other LIN transceiver implementations, which have a V_{CC} supply input instead of a local wake-up input at pin 3. Therefore the wake-up threshold of the WK input is defined to be above 5 V. Thus this pin can be connected to the applications V_{CC} supply without forcing a wake-up event in case V_{CC} drops down (e.g. system sleep mode). Nevertheless this would cause a small extra current consumption $I_{IL(WK)}$ [1] (internal weak current source) of the system.

3.2.4.1 Wake-up after Power-on

After power-on the TLE 7259G enters directly the standby mode and INH is set to HIGH.

3.2.5 INH Pin

3.2.5.1 INH Controlled Voltage Regulator

The output pin INH is a battery related open drain output to control an external voltage regulator. Therefore an external pull-down resistor R_{INH} connected to ground is necessary. This pull-down is typically integrated within the voltage regulator itself. A typical INH pin application is shown in Figure 16a.

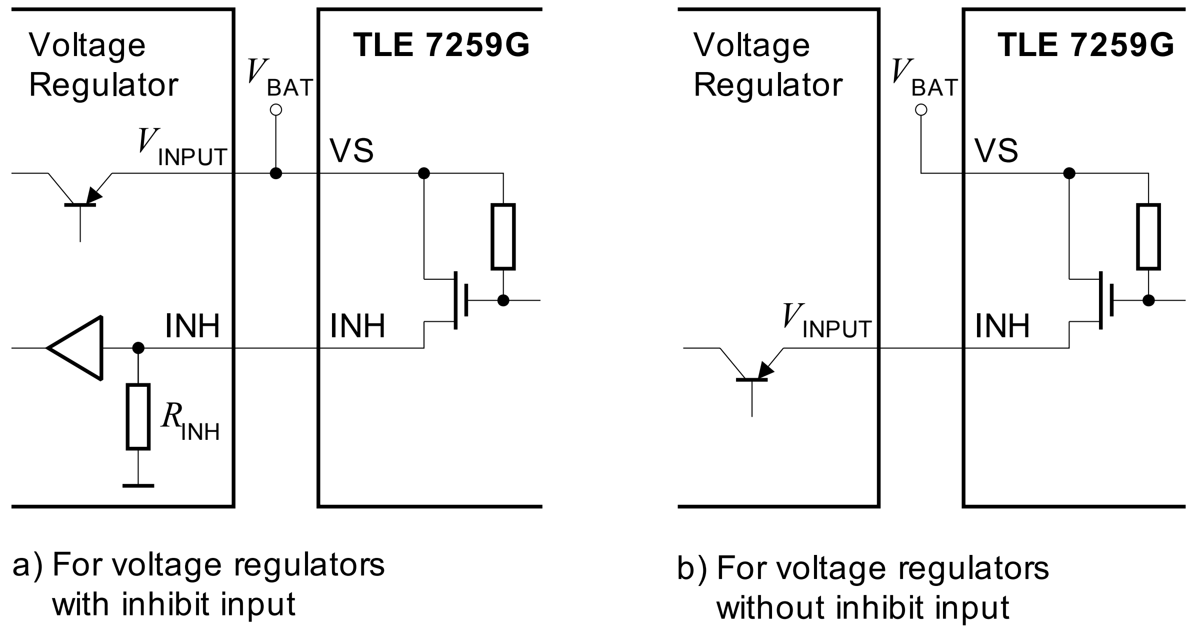


Figure 16 Typical INH Pin Application

The range of the pull-down resistor R_{INH} can be calculated with the equations below:

Range of pull-down resistor:

$R_{INH,\,min} < R_{INH} < R_{INH,\,max}$ with

$$R_{INH,\,min} = \frac{V_{BAT,\,max}}{I_{INH,\,max}}$$

for $I_{INH,\,max}$ see **Chapter 3.2.5.2**

$$R_{INH,\,max} = \frac{V_{LOW(Volt\ Reg),\,max}}{I_{LH(INH),\,max}}$$

with

$I_{LH(INH),\,max}$ maximum INH HIGH-level leakage current **[1]**

$V_{LOW(Volt\ Reg),\,max}$ maximum inhibit LOW-level input voltage (volt regulator)

3.2.5.2 Direct Voltage Regulator Supply

Due to the INH drive capability, the TLE 7259G is able to supply a voltage regulator directly. **Figure 16b** shows the typical INH pin application of such a slave application.

The maximum supply current through the INH pin $I_{INH,\,max}$ for the voltage regulator and the maximum voltage drop V_{DROP} can be calculated by the equations below:

Max. voltage regulator supply current through INH:

$$I_{\mathrm{INH,\,max}} = \sqrt{\frac{P_{\mathrm{max}} - P_{\mathrm{Q,\,max}} - P_{\mathrm{Tx,\,max}}}{R_{\mathrm{SW(INH),\,max}}}} \qquad \text{with} \qquad I_{\mathrm{INH,\,max}} \le 150\ \mathrm{mA}$$

$$P_{\mathrm{max}} = \frac{T_{\mathrm{vj,\,max}} - T_{\mathrm{amb,\,max}}}{R_{\mathrm{th(j\text{-}a)}}}$$

Max. voltage drop at INH:

$$V_{\mathrm{DROP}} = R_{\mathrm{SW(INH),\,max}} \times I_{\mathrm{INH,\,max}}$$

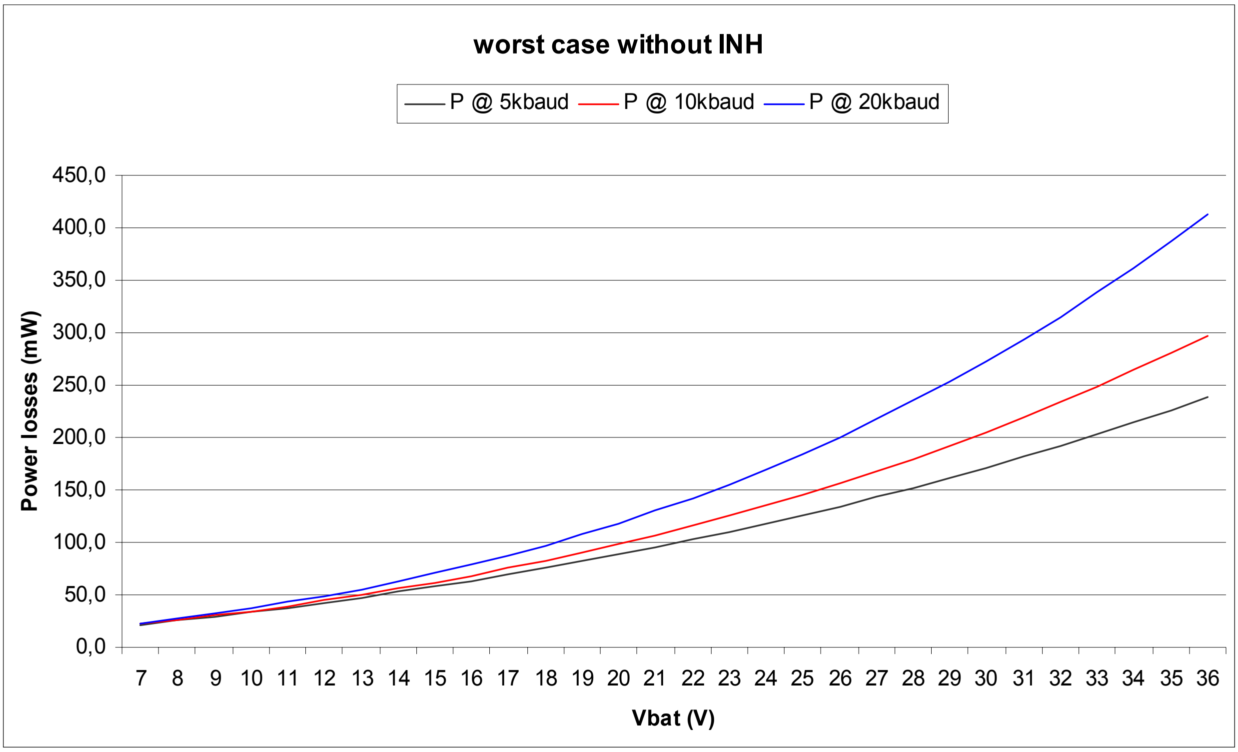
with

P_{Qmax}	maximum quiescence power dissipation (normal slope mode, bus recessive, V_{INH} = V_{BAT}), see **Figure 17**
$P_{Tx,\,max}$	maximum transmitter power dissipation (normal slope mode, transmission duty cycle = 50%, V_{INH} = V_{BAT}), see **Figure 17**
$R_{SW(INH),\,max}$	maximum switch-on resistance between BAT and INH **[1]**
$T_{vj,\,max}$	maximum virtual junction temperature (K) **[1]**
$T_{amb,\,max}$	maximum ambient temperature (K)
$R_{th(j\text{-}a)}$	thermal resistance (K/W) **[1]**

Note: Independently from the above calculation the current through the INH pin I_{INH} should not exceed 150 mA.

The power dissipation depends on the supply voltage V_{BAT} and the baud rate. **Figure 17** shows the quiescence power dissipation P_Q and the transmitter power dissipation P_{Tx} of the TLE 7259G as the function of the supply voltage V_{BAT}. A worst case duty cycle of 50% and a worst case LIN bus load (R_L = 500 Ω, C_L = 10 nF) are used for the transmitter power dissipation R_{Tx} in **Figure 17**.

The thermal resistance $R_{th(j\text{-}a)}$ **[1]** is the ability of an IC package to conduct heat to its environment and is typically specified for free air conditions. Within real applications the use of large copper planes attached to pin GND can reduce the thermal resistance and therefore increase the maximum INH current $I_{INH,\,max}$.



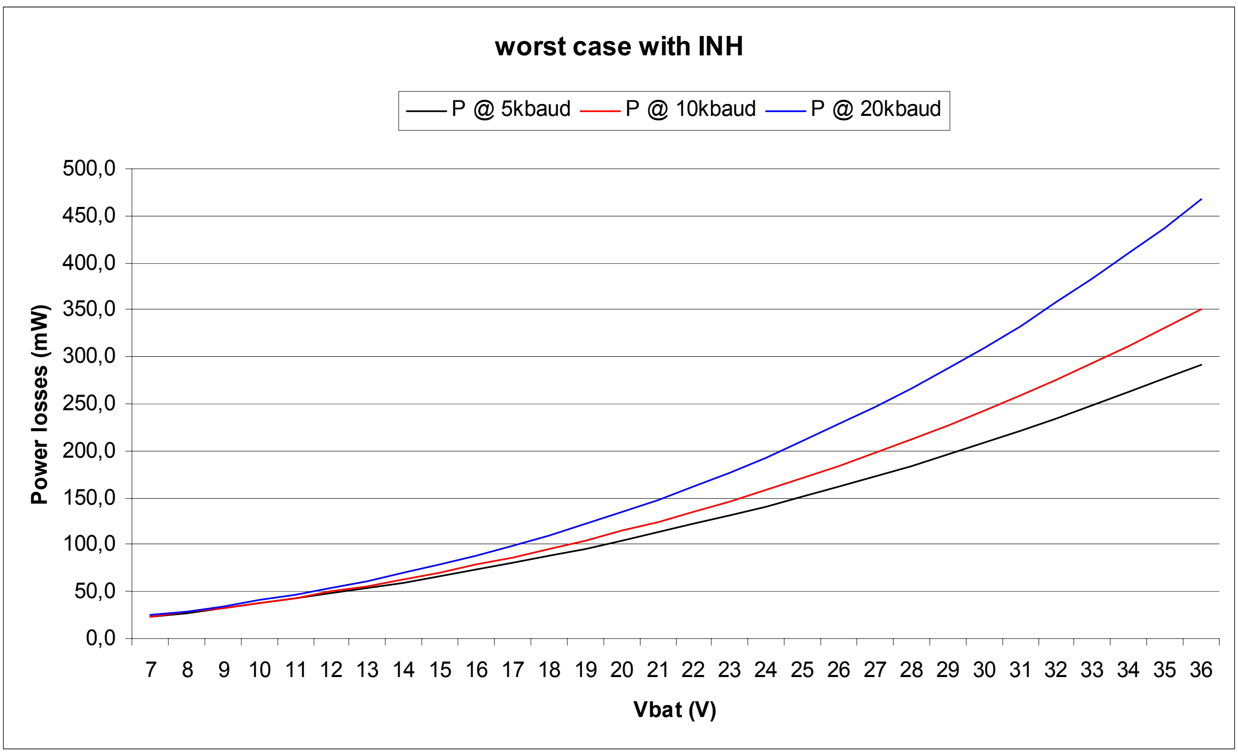


Figure 17 Worst case power Dissipation in Normal Slope Mode

3.2.5.3 Power losses in the master resistor

It´s also important to pay attention to the power losses in master resistor. **Figure 18** shows the worst case values, function of Vbat, for a worst case 900 Ω resistor and duty cycle of 50%.

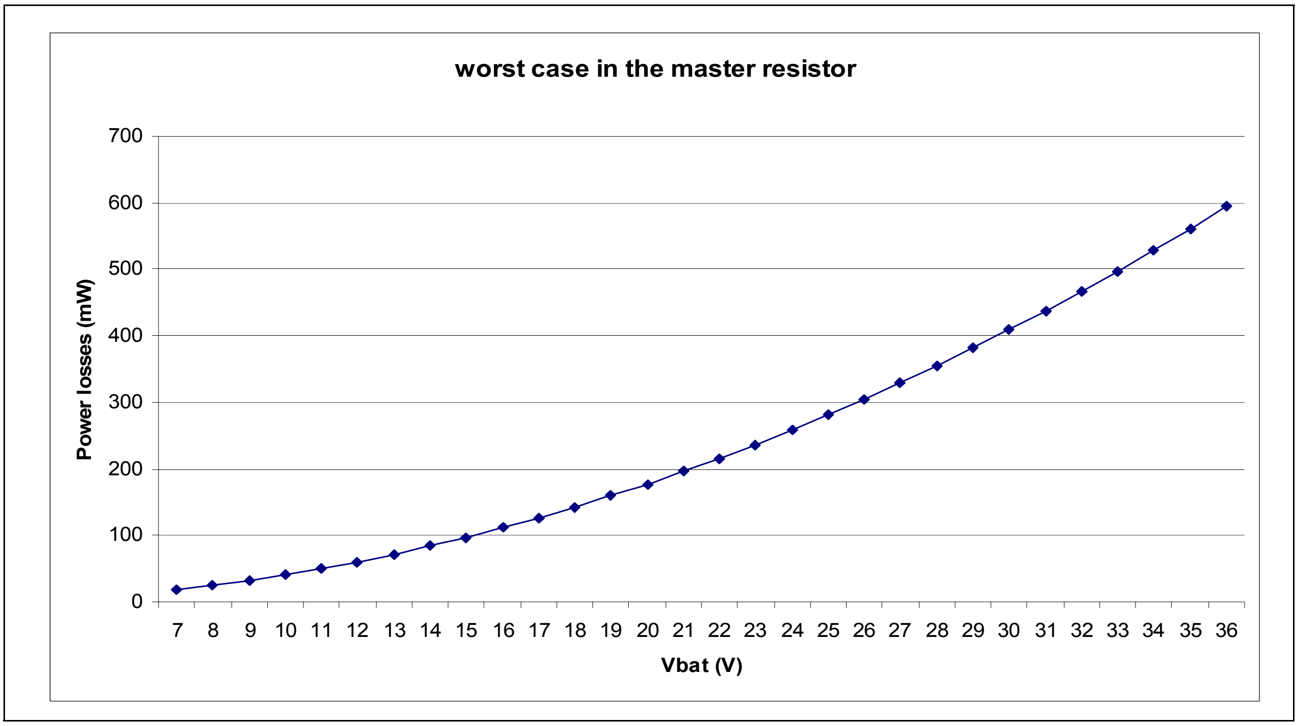


Figure 18 Worst case power losses in the master resistor

3.2.6 BUS Pin

The pin BUS is used to transmit and receive data on the LIN bus line. The transmission is performed by a low side switch with slope control mechanism, and the reception is undertaken by an implemented receiver. The thresholds of the receiver $V_{bus(rd)}$ & $V_{bus(dr)}$ **[1]** are battery related and are linked by an hysteresis of $V_{bus(hys)}$ **[1]**.

The BUS pin has a weak pull-up current source of I_{BUS} **[1]** and a slave termination resistor of R_{SLAVE} **[1]** in parallel to BAT. The slave termination resistor and the current source as well as the low side switch are implemented with a reverse current diode (see also **Figure 19**). Thus no external components are required. Nevertheless, improvement of EME and EMI can be achieved by applying a capacitive load at the LIN bus line as shown in **Figure 11**.

The current source of $I_{BUS(sleep)}$ **[1]** is used as an additional weak pull-up, because the slave termination resistor R_{BUS} **[1]** is switched off in sleep mode. Thus a transition into the sleep mode minimizes the current consumption in case of LIN short-circuit to ground (see **Chapter 8.2**).

4 Master Application

A master application differs from a slave application mainly in the requirement of an additional master termination resistor R_{MASTER} [2]. The capacitance load C_{MASTER} [2] is recommended in order to improve EME as well as EMI (see also **Chapter 5**). The TLE 7259G provides several master application solutions, which are described in the following chapters.

4.1 Master Termination Directly to BAT

This master application is realized by a reverse current diode in series with the resistor R_{MASTER} [2] connected between LIN and BAT as shown in **Figure 19**. The diode should be a standard one with at least a voltage drop of 300mV in the all temperature range like BAS16 from Infineon Technologies.

Such a master application solution does not provide fail-safe system behavior in case the LIN bus is erroneously shorted to ground. This short-circuit current can not be switched off, and will discharge the battery continuously.

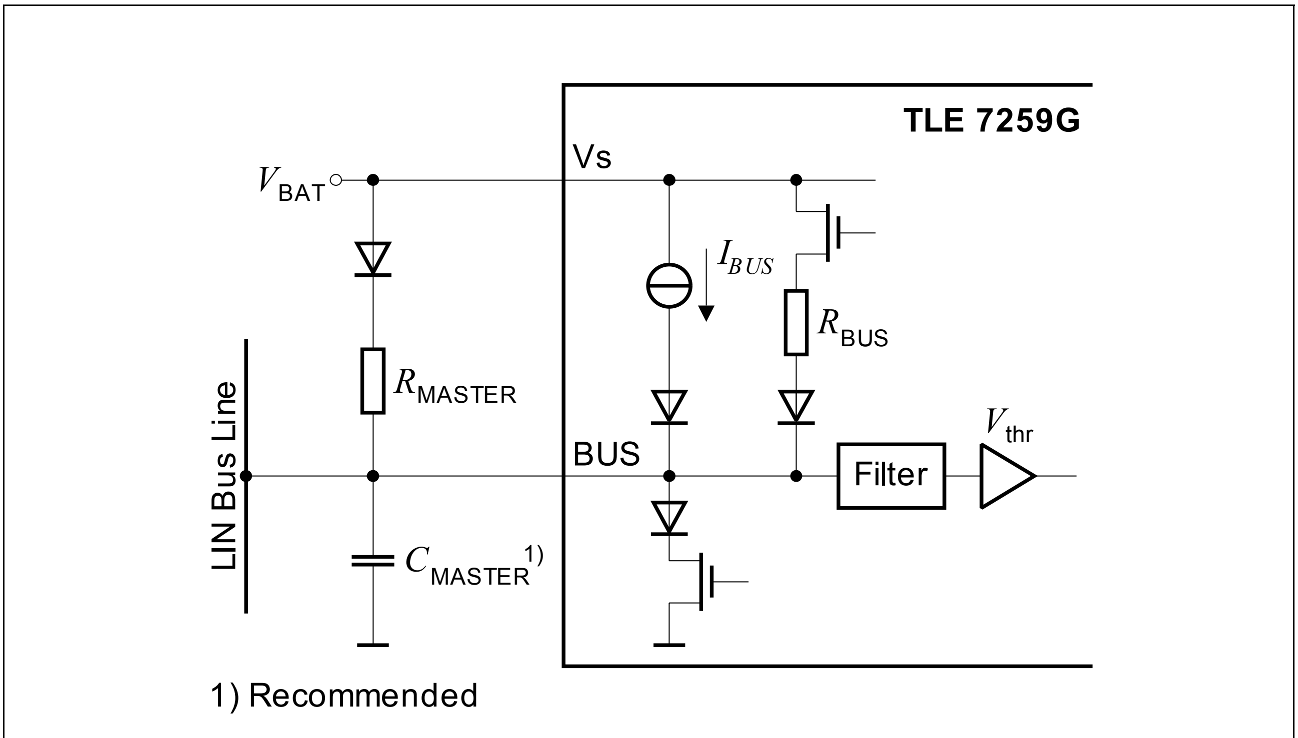


Figure 19 Typical Master Termination

4.2 Master Termination towards INH

For fail-safe reasons the TLE 7259G supports an advanced master application solution using the INH pin to drive the master termination resistor R_{MASTER} [2]. As shown in **Figure 20** the master termination resistor in series with a reverse current diode is connected to the INH pin instead of the BAT pin. The advantage of this application solution is the ability to switch off the master termination by a transition into the sleep mode, thus solving the above mentioned short-circuit condition of LIN and ground.

Whenever the applications micro controller detects a permanent dominant level on the LIN bus line caused by a ground short-circuit, the micro controller is able to minimize the power dissipation by selecting the sleep mode. Thus a transition into the sleep mode switches off the external voltage regulator, the master termination R_{MASTER} [2] as well as the internal slave termination R_{BUS} [1]. Only the internal weak pull-up current source I_{BUS} [1] and the internal current consumption of the TLE 7259G determine the remaining current consumption of a LIN node in such a failure case (see also **Chapter 8.2**).

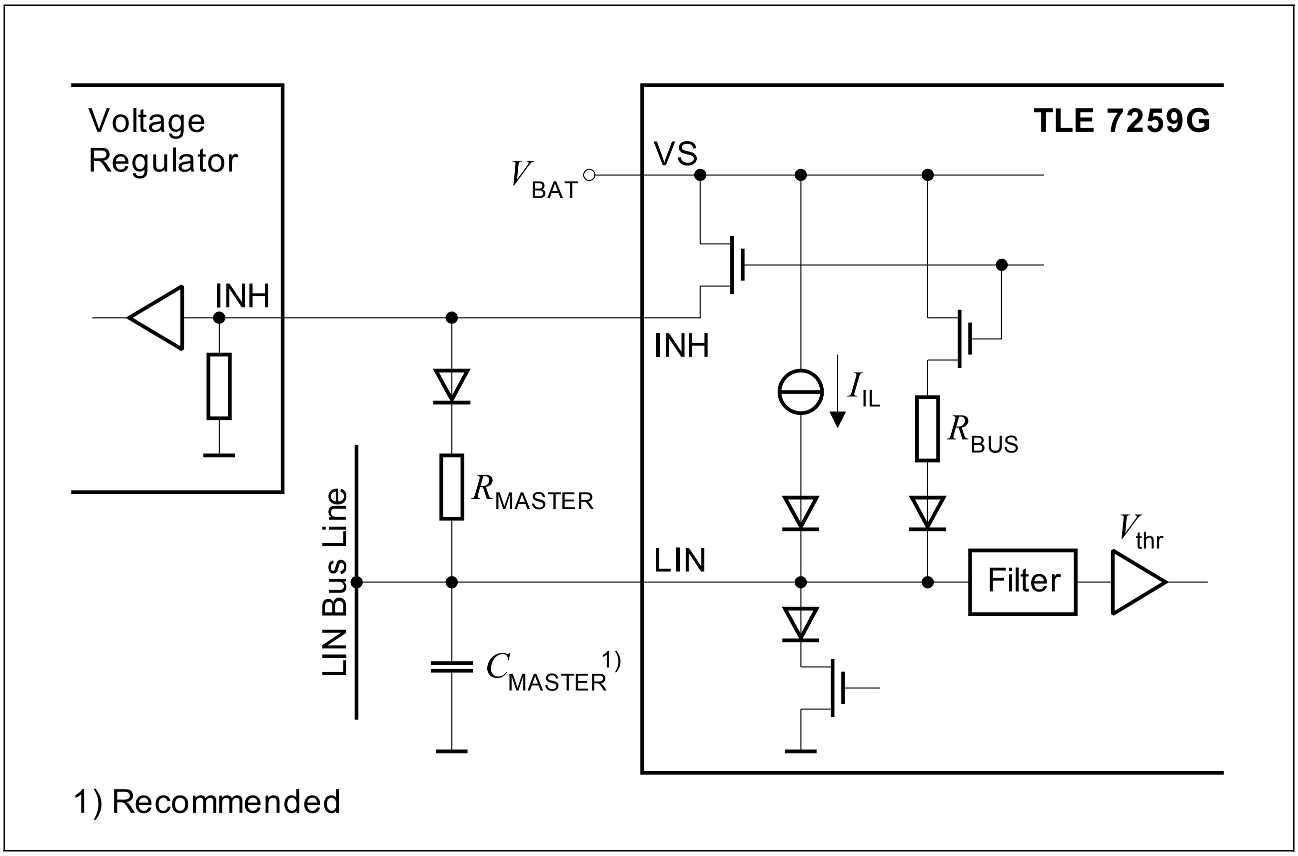


Figure 20 Advanced Master Termination through the INH Pin

4.3 Master Termination Split between INH and BAT

Since the advanced master termination in **Chapter 4.2** provides a fail-safe system behavior but high LIN bus impedance in sleep mode, a combination of the terminations concepts in **Chapter 4.1** and **Chapter 4.2** can be an option, if a higher short-circuit current at the LIN bus can be tolerated (see **Figure 21**).

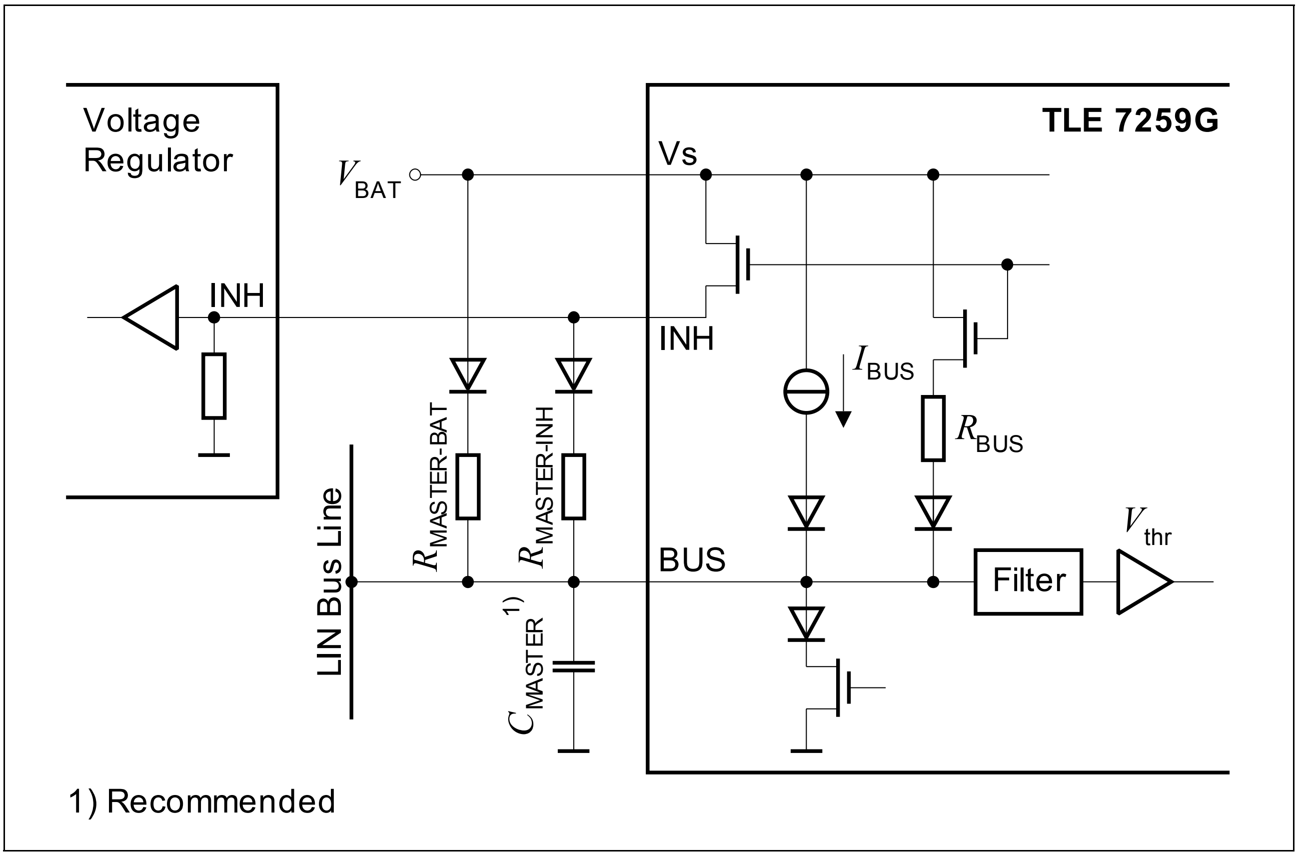


Figure 21 Trimmed Master Termination

The resistors $R_{\text{MASTER-BAT}}$ and $R_{\text{MASTER-INH}}$ in parallel determine the master termination while the TLE 7259G is in its modes: standby, normal slope and low slope. In sleep mode the master termination is determined by $R_{\text{MASTER-BAT}}$. Therefore the maximum LIN bus short-circuit current $I_{\text{SC, max}}$ can be trimmed by $R_{\text{MASTER-BAT}}$

$$R_{\text{MASTER-BAT}} = \frac{V_{\text{BAT, max}}}{I_{\text{SC, max}}}$$

$$R_{\text{MASTER-INH}} = \frac{R_{\text{MASTER-BAT}} \times R_{\text{MASTER}}}{R_{\text{MASTER-BAT}} - R_{\text{MASTER}}} \quad \text{with} \quad R_{\text{MASTER}} = 1\ \text{k}\Omega$$

5 EMC Aspects

The board layout has a strong influence on the ESD and EMC performance. The result is a recommendation based on measurements on a dedicated board. The tests have to been performed on the used hardware.

5.1 EMI - Capacitive Load

A capacitor on the LIN bus pin reduces the impact of RF-interferences. Thus it is recommended to provide a capacitor (e.g. $C_{MASTER/SLAVE}$ = 220 pF) from BUS to ground at each node.

5.2 ESD aspect

The TLE 7259G has an integrated protection against ESD. The performance of the device is specified in the Data Sheet. The specification is done based on the HBM (Human Body Model).To improve the ESD performance on board level and to withstand higher limits especially with GUN tests according to IEC 61000-4-2, please refer to the **Figure 22**and **Figure 23**. With this recommended circuit, an ESD performance higher than ± 8KV (GUN 330Ohm/150pF) has been achieved.

5.2.1 Application with capacitors

The 100nF ceramic capacitor (0805 footprint) with 4ohm resistor has been tested in the application and shows positive results.1

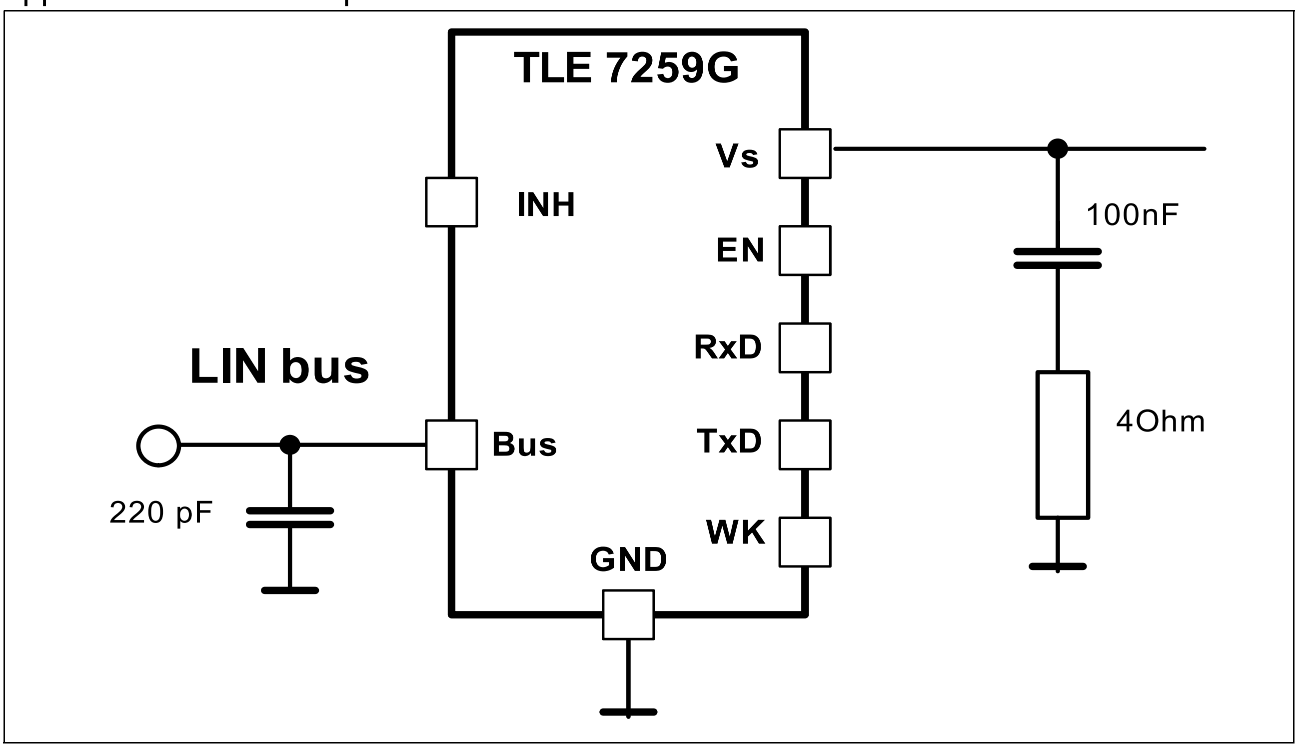


Figure 22 Application with blocking capacitor to improve ESD robustness

5.2.2 Application with varistor

The use of a varistor as described in Figure 23 AVR-M1608C270MBAAB (27V/30pF) at the LIN bus achieves a result of +/- 12kV.

In case of use of a varistor, the C_{LIN} capacitor has to be recalculated to fit the 5µs maximum of the LIN requirement.

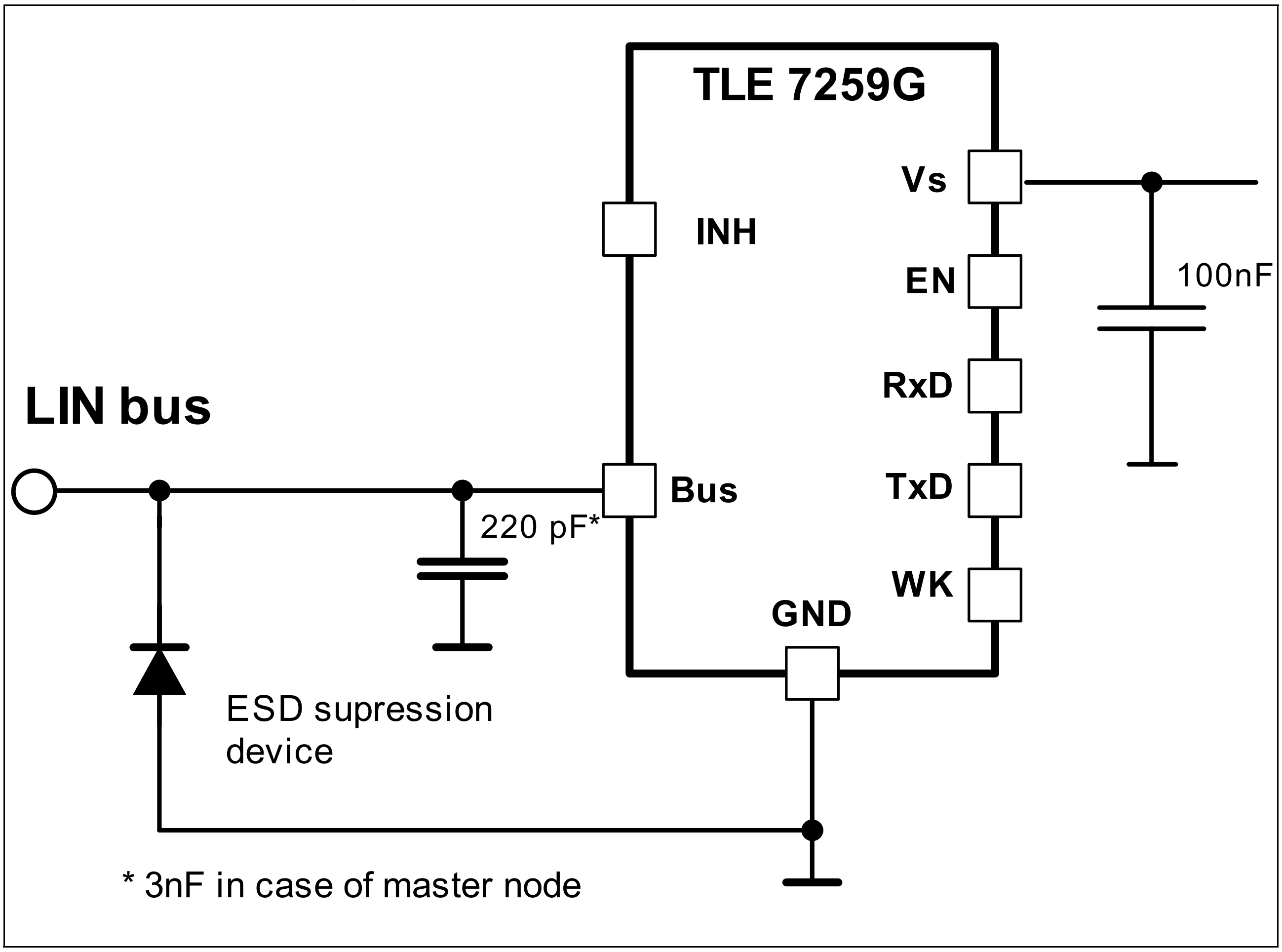


Figure 23 Application with varistor

5.3 Module protection against ESD

In case of an ESD event a very high current flows into the LIN-transceiver TLE 7259G. A very low ohmic ground wire is recommended to reduce the voltage drop in case of the ESD event. This is necessary to guarantee the excellent ESD behavior of the TLE 7259G. Figure 24 shows and optimized ESD application circuit and Figure 25 shows the critical problem in case of ESD

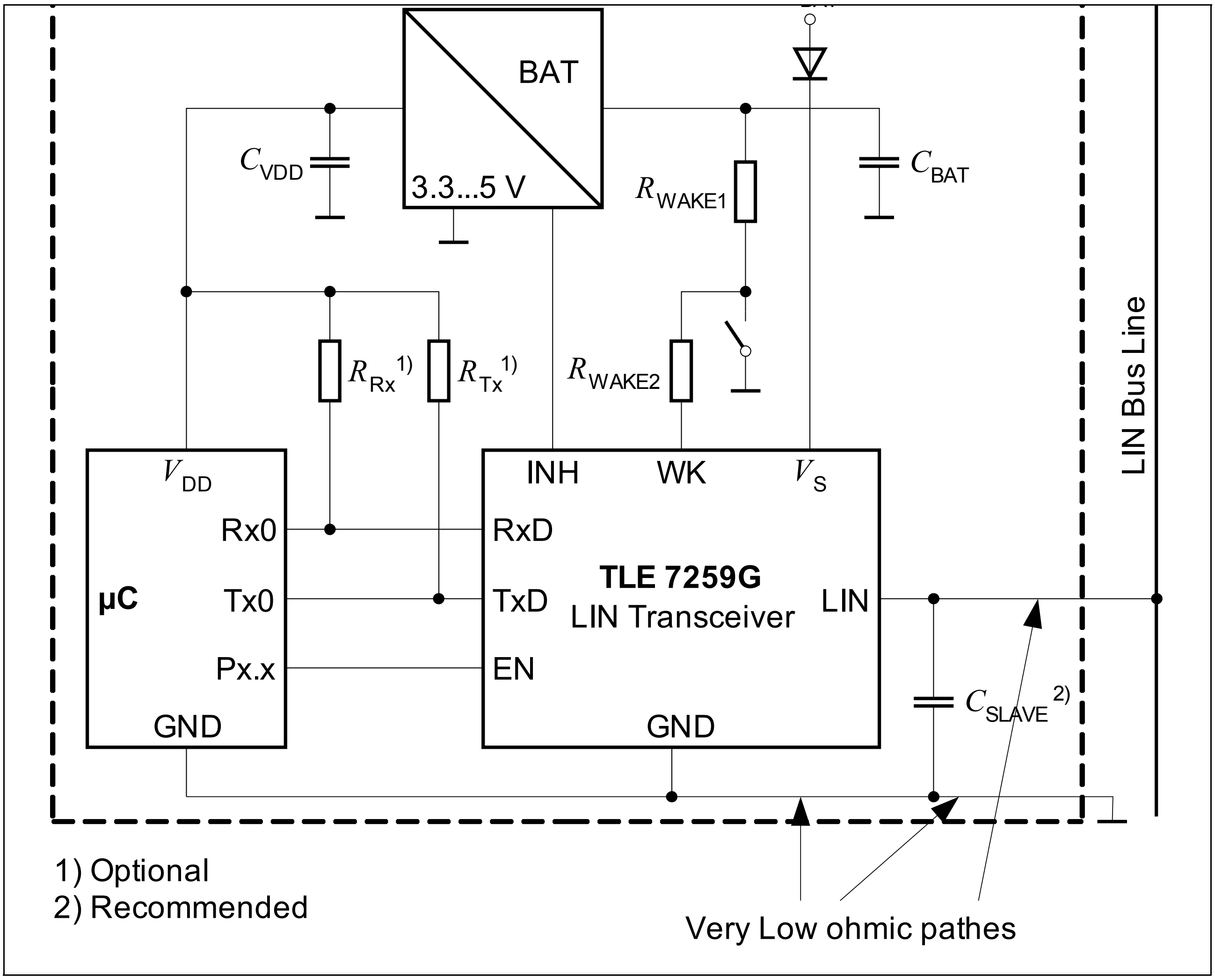


Figure 24 Application proposal for good ESD behavior of the module

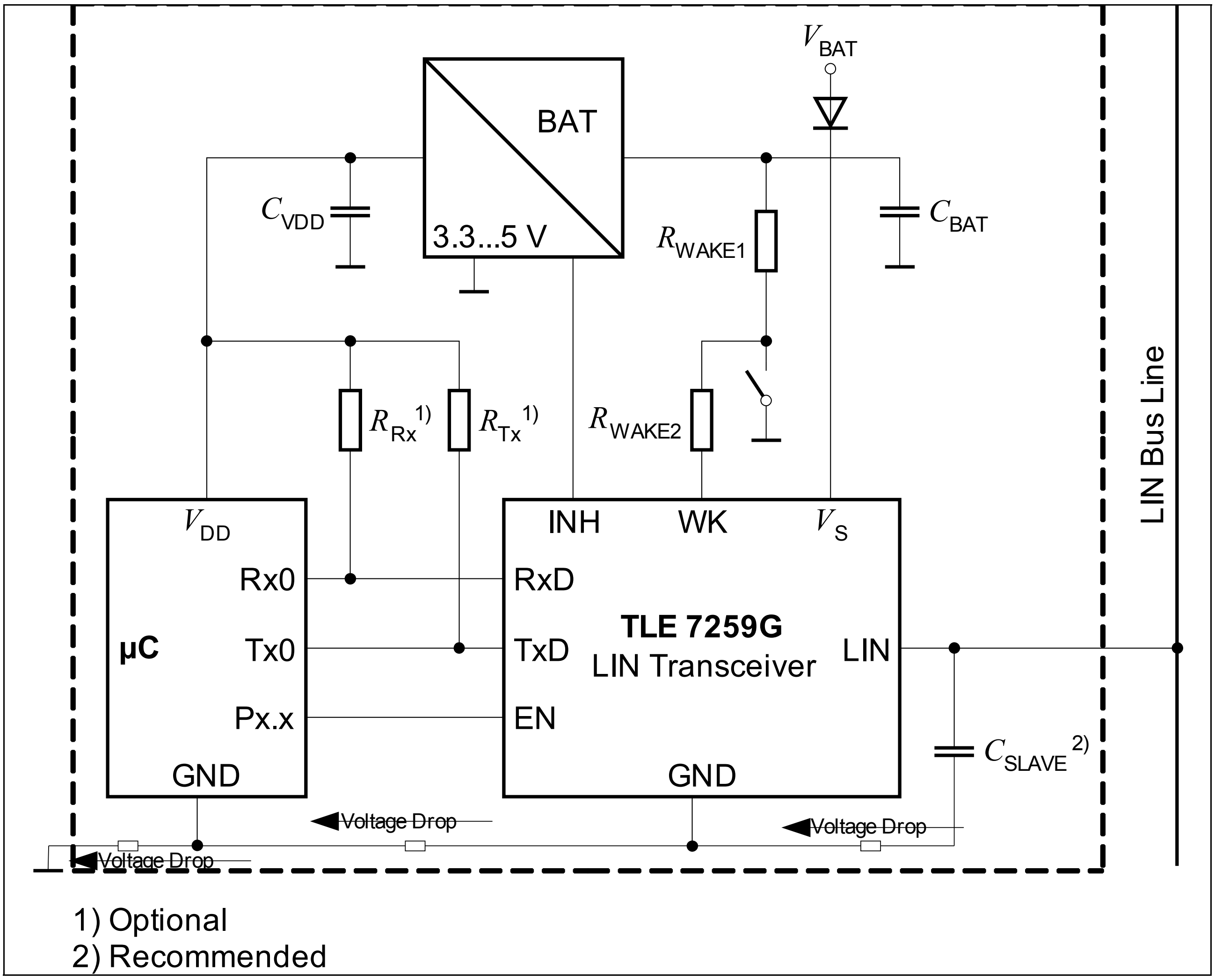


Figure 25 Typical ESD issue at module level description

5.4 EMI measurements

5.4.1 EMI measurements with termination capacitor.

Figure 26 shows the behavior of the TLE7259G during the DPI measurement. No special component are implemented, except a 220pF bus termination capacitor.

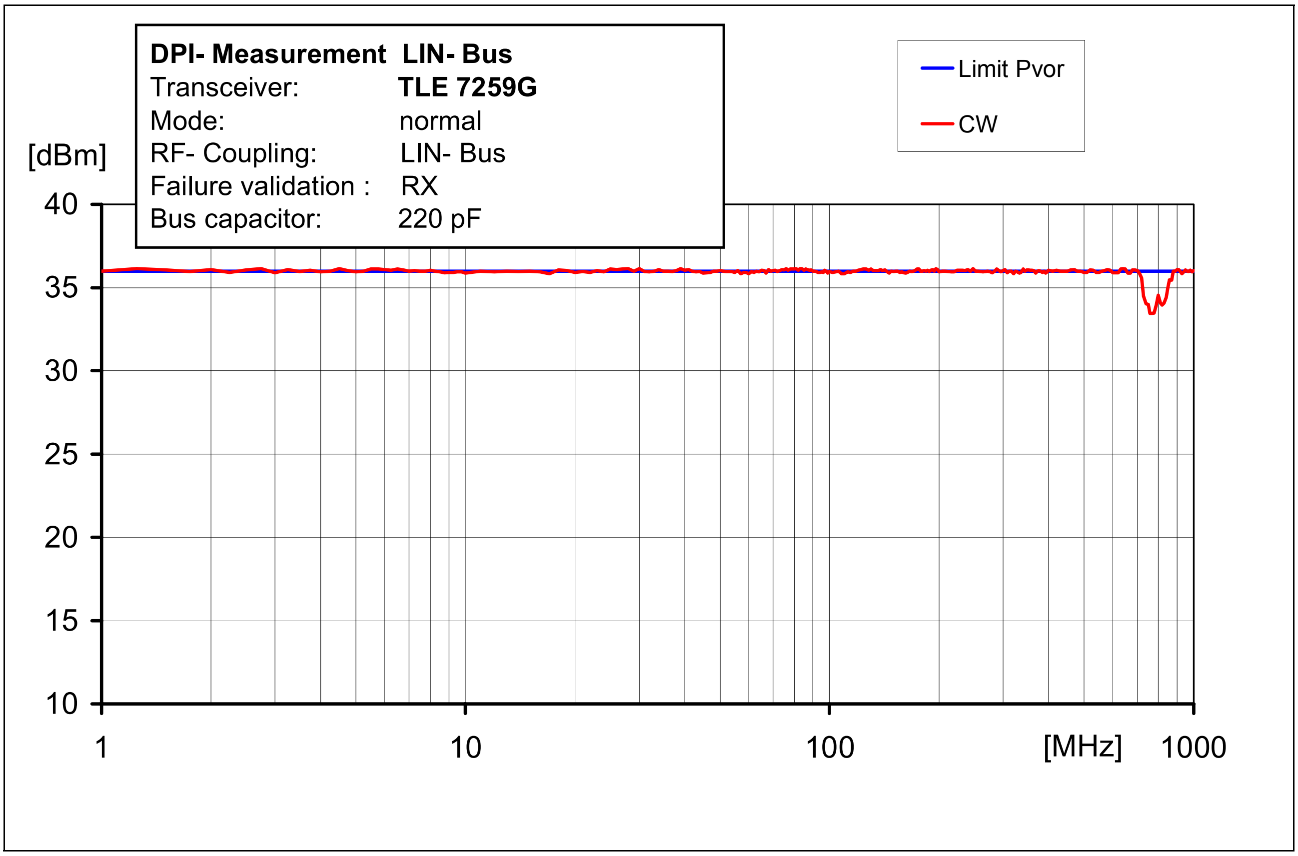


Figure 26 DPI measurement with bus termination capacitor

5.4.2 EMI measurements with ferrite and/or varistor.

On **Figure 27** is shown the result with the varistor described in **Chapter 5.2.2** and also with the use of a ferrite MMZ2012Y202B.

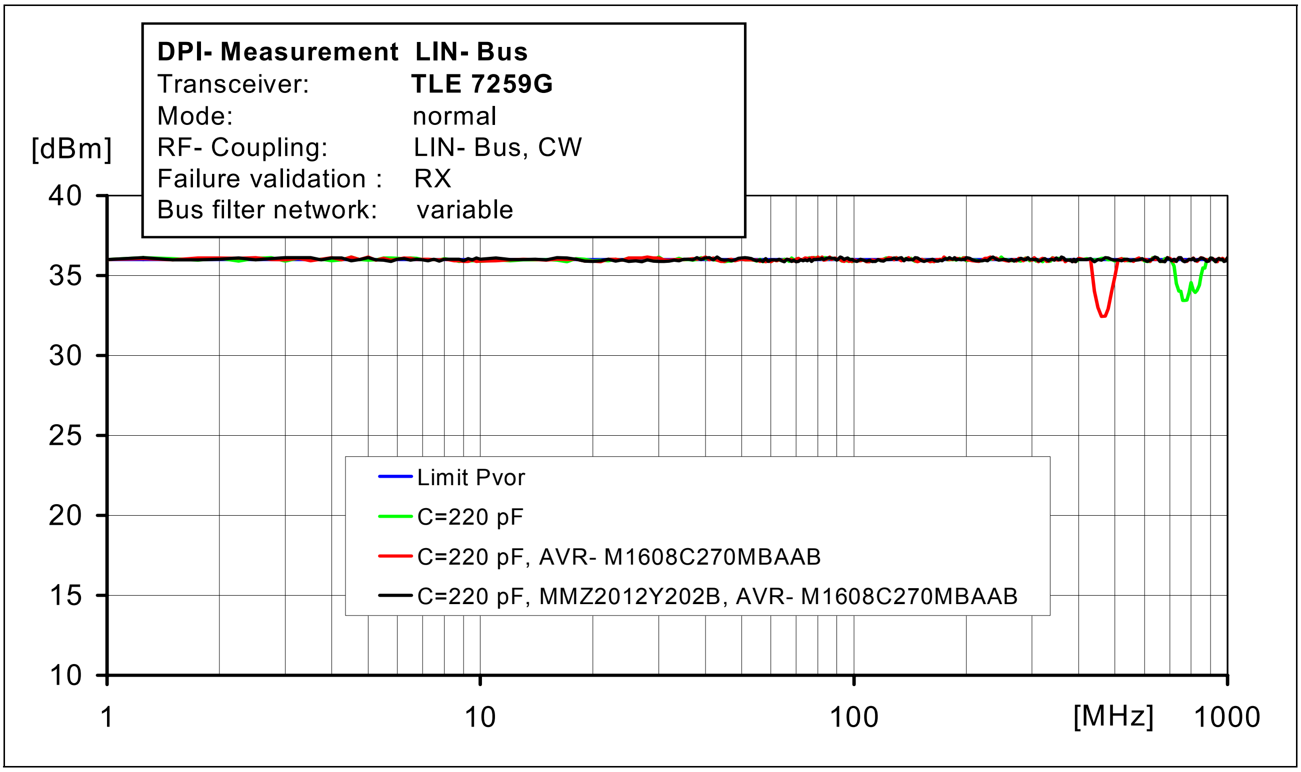


Figure 27 DPI measurement with bus termination capacitor

5.5 EME - Slope Control

The LIN physical layer is a single-wire, wired AND bus with a battery related recessive level. Here, no compensation effect of the electromagnetic field is present as known from dual-wire concepts making use of differential signals (e.g. High-Speed CAN). Thus a smooth output wave shaping becomes more important. The Electro Magnetic Emission EME depends mainly on the falling and rising slope of the LIN bus waveform. The weaker these slopes are the more EME reduction can be achieved.

The TLE 7259G provides a slope control adjustment by modifying the capacitive load (C_{MASTER} **[2]** or C_{SLAVE} **[2]**) on the LIN bus. The slope decreases with increasing capacitive load. Therefore increasing the total network capacitance ($C_{BUS} = C_{MASTER} + n \times C_{SLAVE} \times C_{LINE}$ **[2]**) can further reduce the EME. For very high bit rates close to 20 kBaud the LIN bus slope times have also impacts to system tolerances such as ground shift. Thus it is not recommended to make use of the maximum allowed capacitive load $C_{BUS, max}$ **[2]** at very high bit rates in order to keep some safety margin for the system. **Figure 28** gives the results observed for the different setups describes in the **Chapter 5**

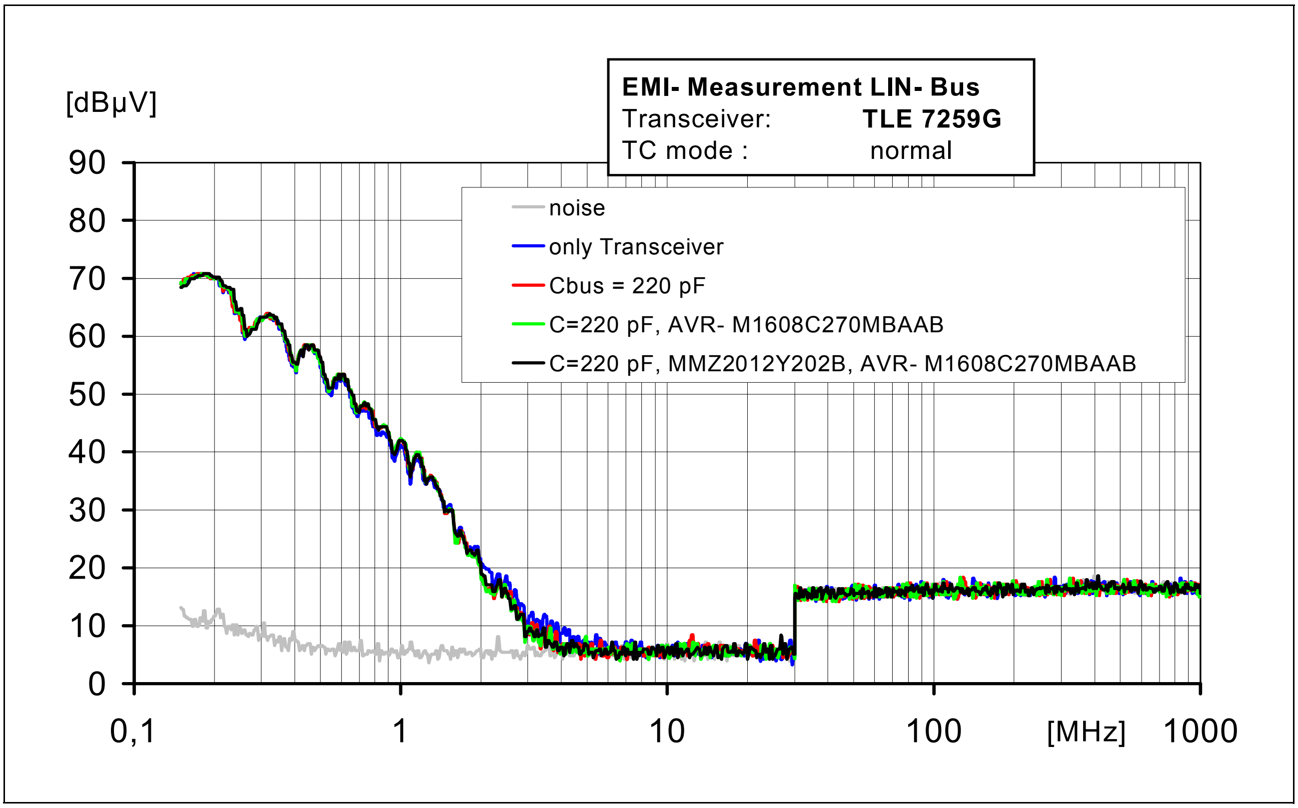


Figure 28 Emission measurements

6 Transceiver Control

The modes of the TLE 7259G are controlled by the pins EN and TxD. The following chapters describe the mode control of TLE 7259G and how to deal with LIN bus failures.

The transceiver control can be split into two basic applications:

- The micro controller power supply is controlled via the INH pin of the TLE 7259G
- Independent of the TLE 7259G's modes the micro controller is permanently supplied.

6.1 INH Controlled Micro controller Power Supply

After a local or remote wake-up the standby mode is entered automatically. As a result the INH pin outputs a battery related high level and thus switches on the external voltage regulator. In consequence the micro controller becomes supplied and starts with its booting. The TLE 7259G indicates the wake-up event by an active low at RxD.

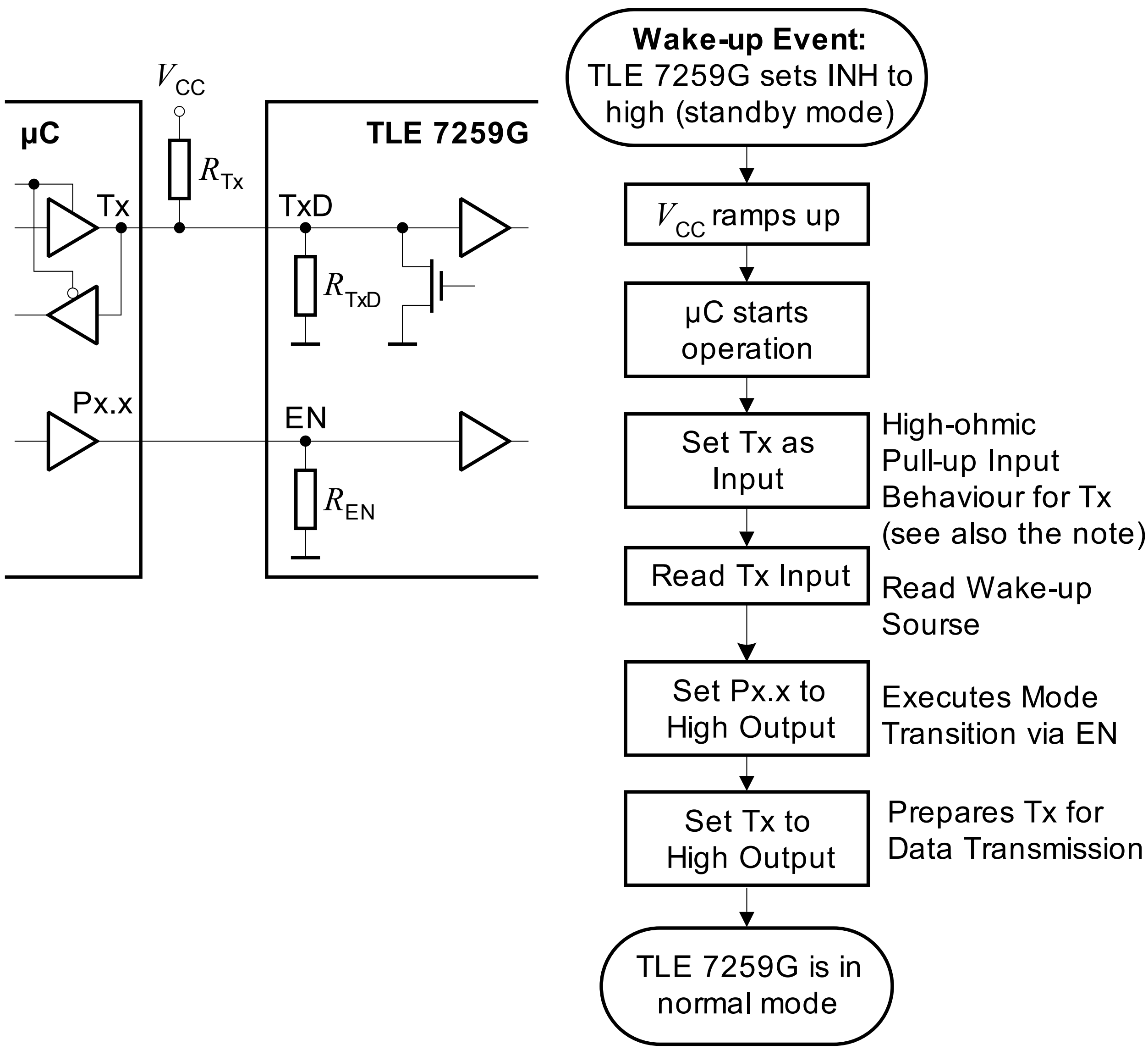
6.1.1 Applications Using EN

The TLE 7259G allows distinguishing between different wake-up sources using the TxD pin. Thus the TxD pin needs to be applied with a pull-up behavior as described in **Chapter 3.2.2**. This pull-up behavior is required to sense the TLE 7259G's pull-down transistor at TxD, which becomes active after a local wake-up event via EN. Thus the wake-up source can be distinguished by reading the TLE 7259G's TxD pin.

TxD gets high automatically after a local wake-up event if the corresponding micro controller port pin is configured to be input (weak high) because the wake-up source information is cleared immediately with setting EN to high level.

Note: There is no software timing constraint required for setting the micro controller port pin Tx to high output after setting EN to high, because the local wake-up source information at TxD is cleared immediately with setting EN to high level.

Figure 29 shows the related software flow of a standby to normal operation transition.



Note:
The time the Tx pin of the microcontroller is programmed to be input, it behaves high-ohmic. So the external pull-up behaviour is required to pull this pin high in case a remote wake-up has occurred via LIN.

Figure 29 Flow Diagram of Standby to Normal operation Transition, Using WK

6.1.2 Applications without Using WK

In case no local wake-up source is present the hardware becomes simpler because the TxD pin of the TLE 7259G behaves as input only. Thus the weak pull-up behavior as described in **Chapter 6.1.1** is not required.

The software flow is shown within **Figure 30**. Here the TxD input of the TLE 7259G defines the next mode before the EN input is set to a high level.

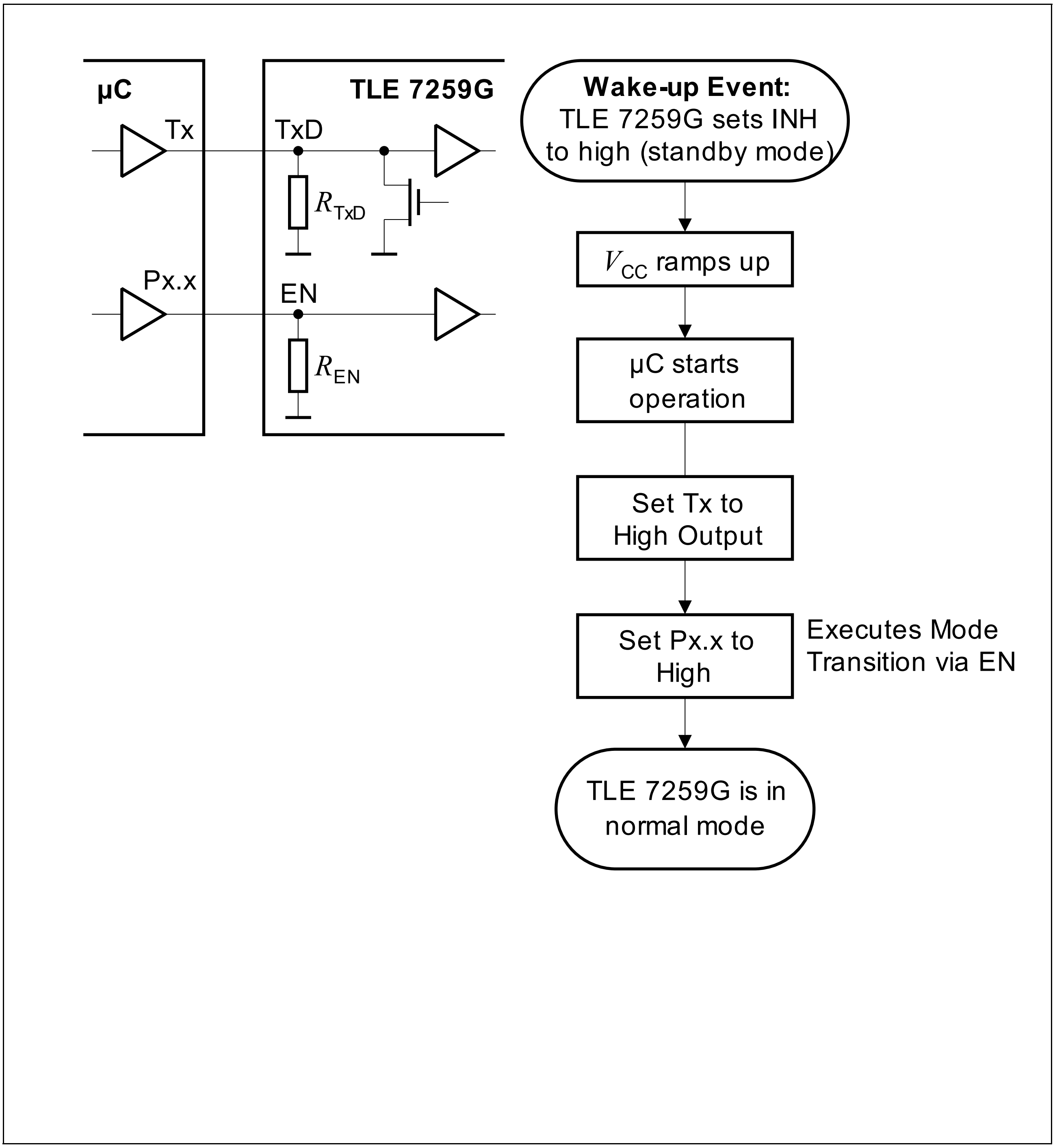


Figure 30 Flow Diagram of Standby to Normal Transition, WK not Used

6.2 Permanently Supplied Micro controller

In some applications the TLE 7259G is not used to control the power supply of the micro controller. Thus the INH pin is unused, respectively used for another purpose. For such applications the TLE 7259G allows a direct transition from sleep mode into normal mode.

6.2.1 Application Using WK

Here the same flow is used as described within **Chapter 6.1.1**. The only difference is that no booting phase is performed, because the micro controller is already running. **Figure 31** shows the related software flow diagram with respect to the pin description of TxD in **Chapter 3.2.2**.

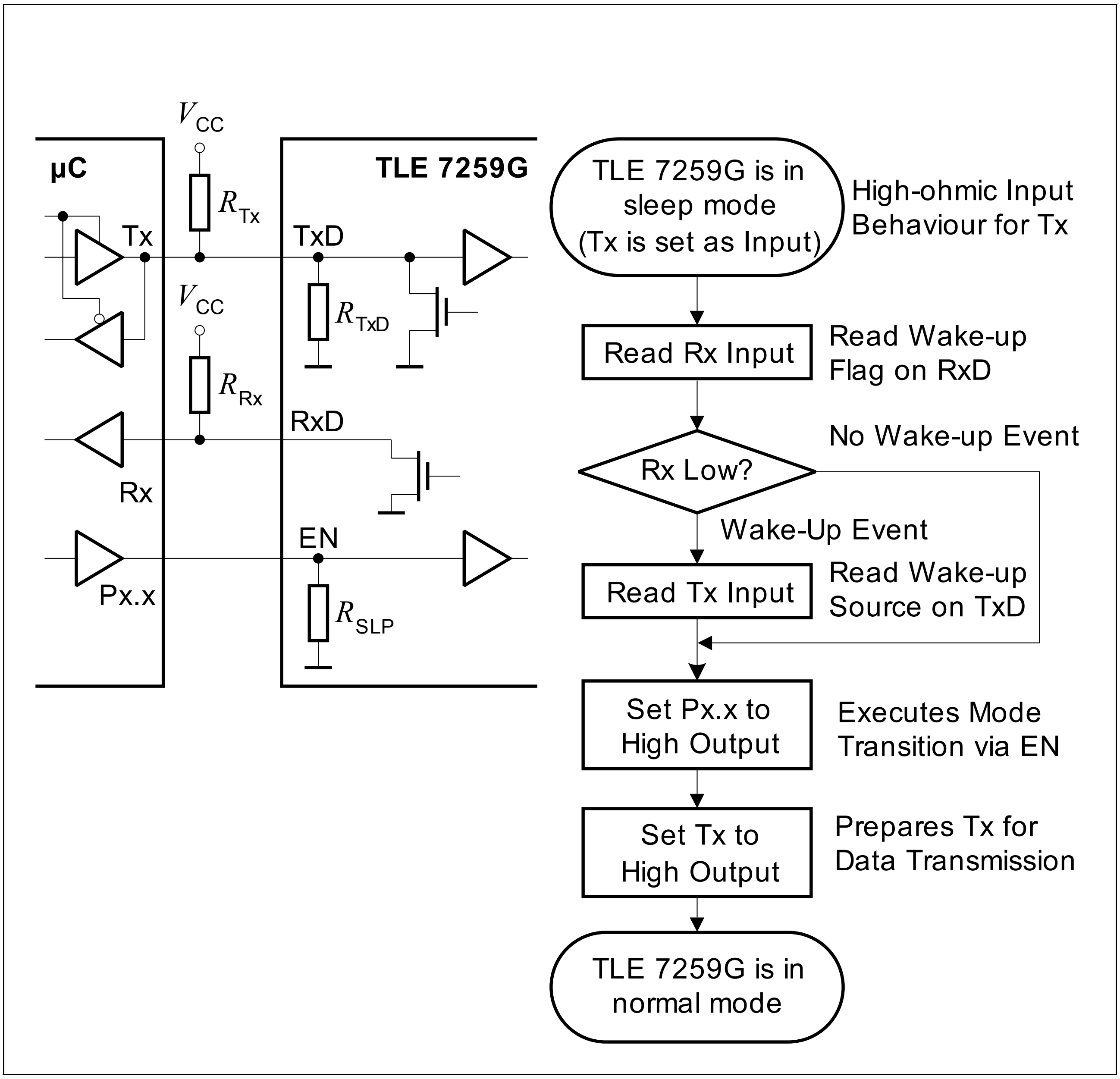


Figure 31 Flow Diagram of Sleep to Normal mode Transition, Using WK

6.2.2 Application without Using WK

Here the same flow is used as described within **Chapter 6.1.2**. The only difference is that no booting phase is performed, because the micro controller is already running. The corresponding software flow diagram is shown in **Figure 32**.

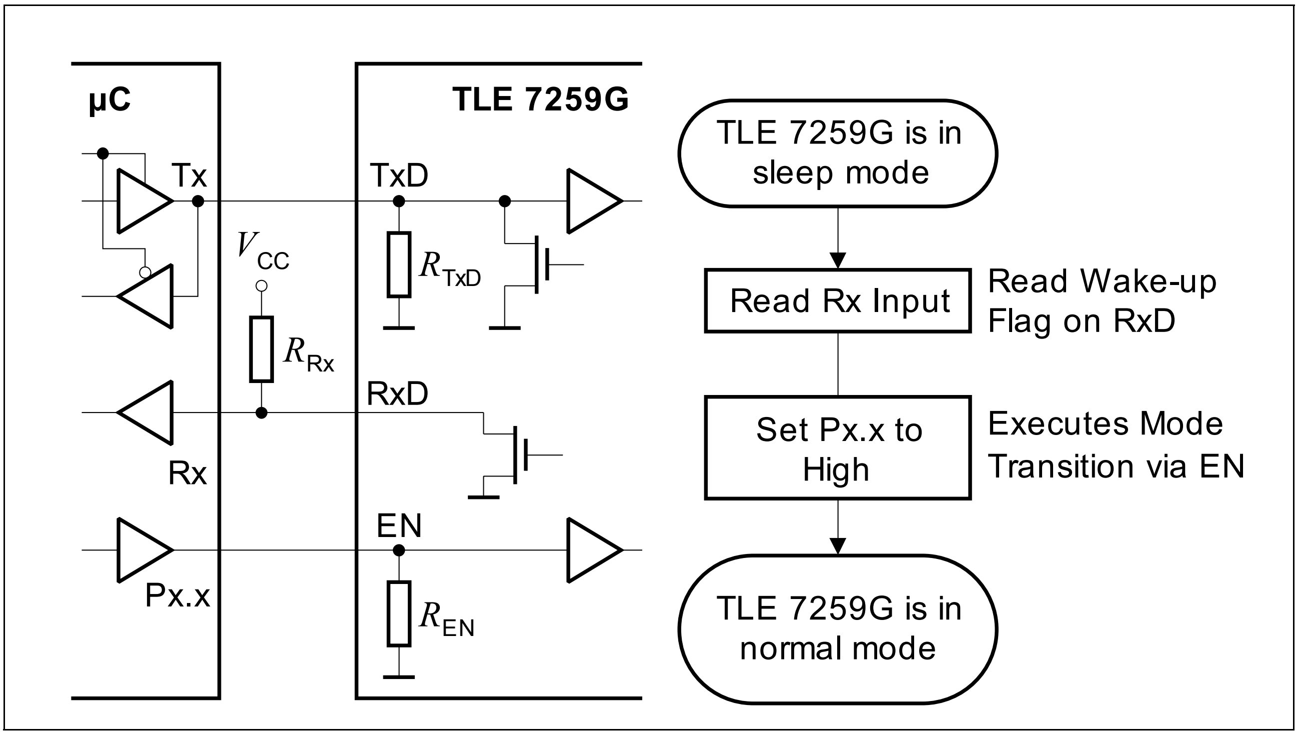


Figure 32 Flow Diagram of Sleep to Normal Mode Transition, WK not Used

6.3 Transition from Normal mode into Sleep Mode

The TLE 7259G enters its sleep mode if the EN input is becoming low for at least $t_{gotosleep}$ [1]. Depending on the use of the WK pin two different software-flows for mode control are recommended.

6.3.1 Application Using WK

If the WK input of the TLE 7259G is in use, the micro controller port pin (e.g. Tx) driving the TxD pin of the TLE 7259G should be configured as input or bi-directional before the mode transition is executed by setting a low level on EN. This provides pull-up behavior at pin TxD in case of wake-up events via WK during mode transition towards sleep mode. **Figure 33** shows the software flow diagram of a transition from normal slope mode or low slope mode into sleep mode with WK support.

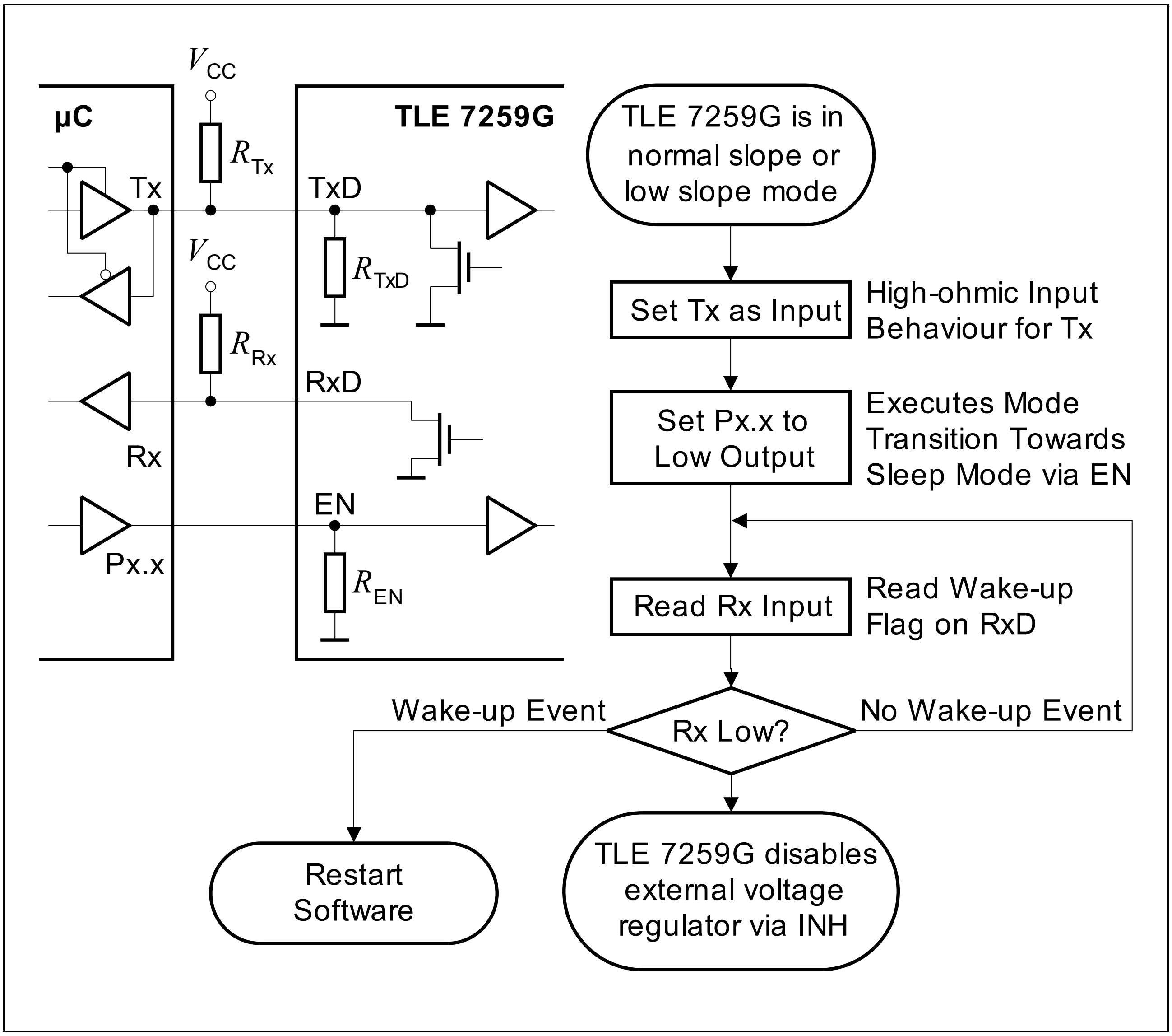


Figure 33 Flow Diagram of Normal/Low Slope to Sleep Transition, Using WK

6.3.2 Application without Using WK

In case the WK pin is unused and no TxD pull-up behavior is provided (see also **Chapter 3.2.2.1**), only the EN input should become low (see **Figure 34**). The "Set Tx as Input" step within the software flow diagram in **Figure 33** should not be performed, since the weak pull-down R_{TxD} **[1]** would cause a low level on TxD if the micro controller port pin Tx is set into a high-impedance state without pull-up behavior. This would result in a dominant level on the LIN bus until EN is set low or the TxD dominant time-out phase is passed.

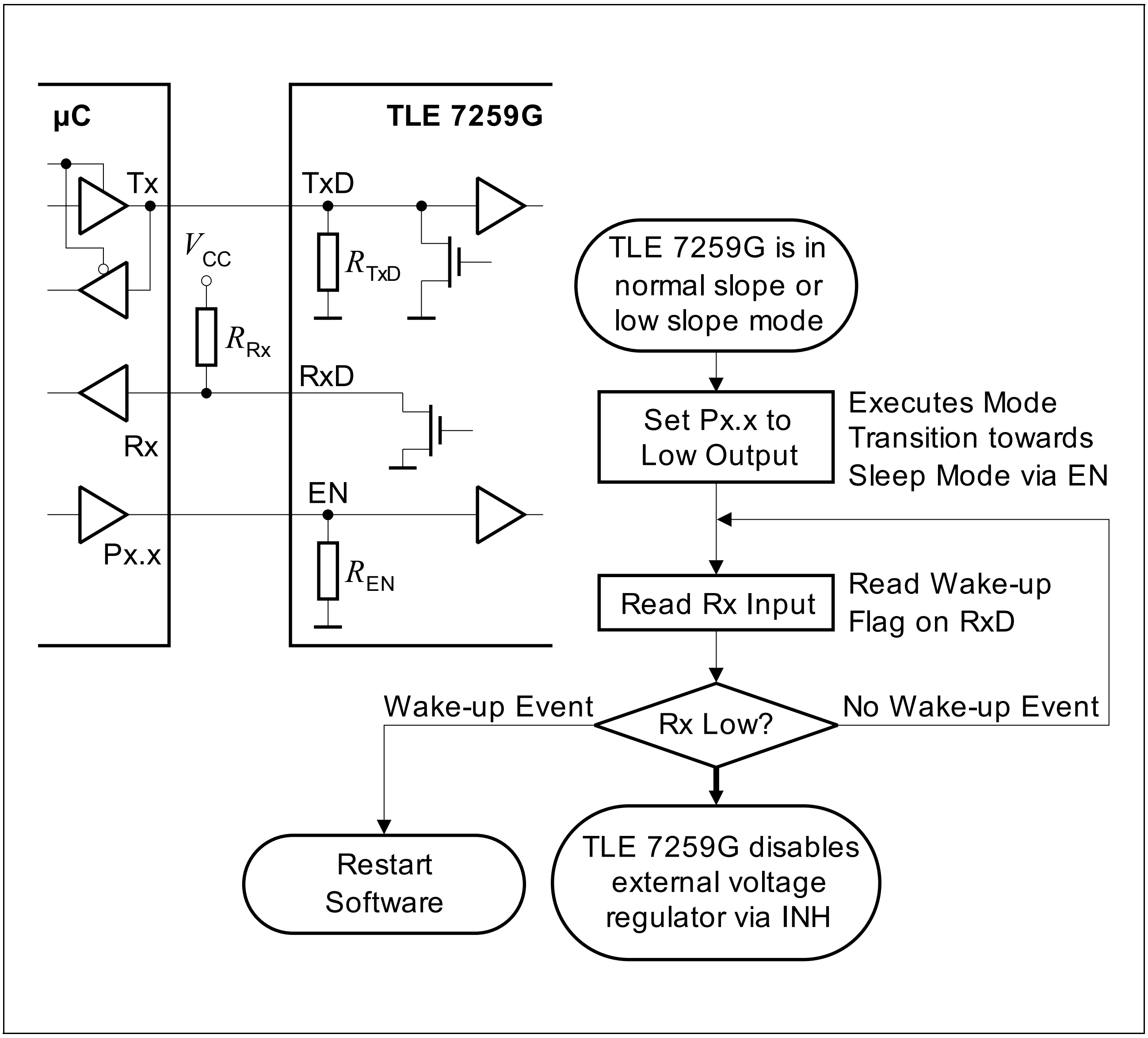


Figure 34 Flow Diagram of Normal/Low Slope to Sleep Transition, WK not Used

7 Failure Management

7.1 LIN Bus Short-Circuit to Ground

In case the LIN bus is shorted to ground a continuous current flows out of V_{BAT} due to the LIN termination. The TLE 7259G allows to reduce this short-circuit current to a minimum using its integrated termination control.

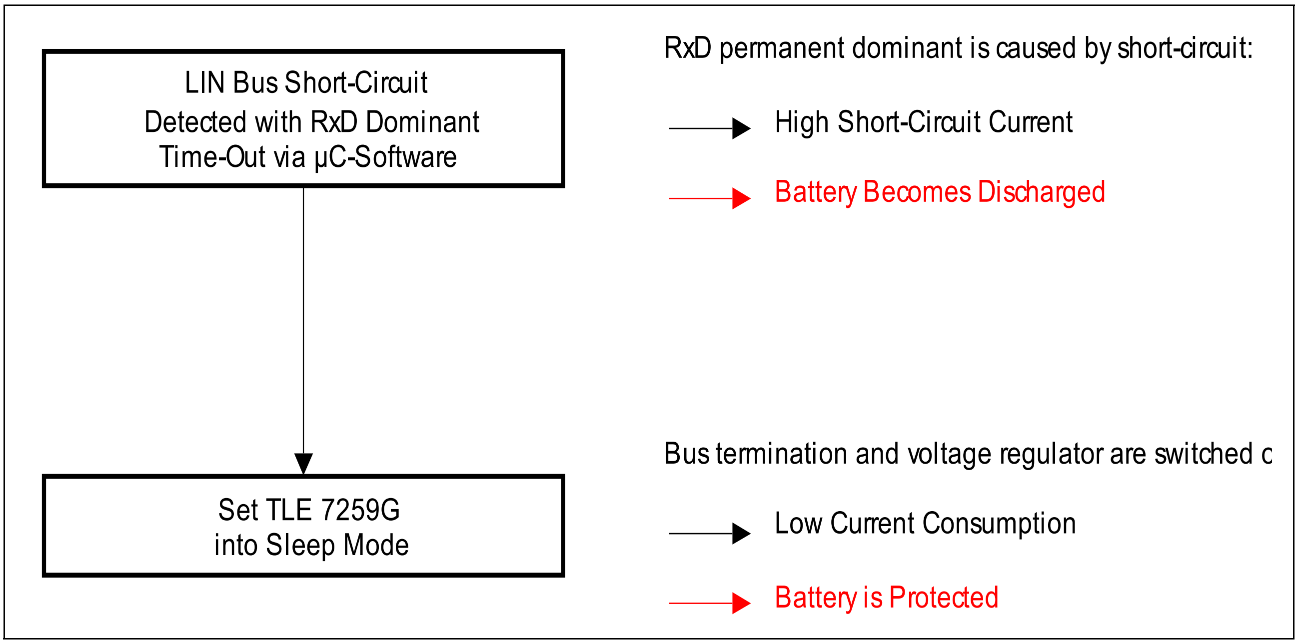


Figure 35 Failure Management if LIN Bus is Shorted to Ground

Once the LIN bus is shorted to ground this can be detected in software monitoring the continuous dominant level on RxD.

In order to reduce this failure current the TLE 7259G is simply put into its sleep mode if not needed anymore. This results in disabling the slave termination resistor R_{SLAVE} **[1]** as well as the external master termination resistor R_{MASTER} if connected to INH. Only an internal weak pull-up current source $I_{IL(LIN)}$ **[1]** remains active for the case of a LIN bus failure recovery. So the INH-controlled master termination resistor R_{MASTER} optimizes the system with respect to fail-safe behavior. Thus the system enters its low power mode ($V_{CC,\ Off}$). The remaining short-circuit current is the amount of the internal bias current and the pull-up current source $I_{IL(LIN)}$ **[1]**. **Figure 35** shows the corresponding failure management flow.

7.2 TxD Dominant Failure

Usually in case a TxD pin is shorted to ground, the LIN bus is clamped to the dominant level and therefore overrules any transmission on the LIN bus. To protect the LIN bus from being continuously driven to the dominant level, the TLE 7259G has an integrated

TxD dominant timer. Thus the transmitter of the TLE 7259G is disabled if a TxD dominant failure is detected, and the LIN bus is released again.

Due to the integrated pull-down TxD resistor R_{TxD} [1], an open TxD pin results also in a continuous dominant situation. In such a case the TxD open failure is detected by the integrated TxD dominant timer and disables the transmitter stage of the TLE 7259G.

Both failures, the TxD dominant failure as well as the TxD open failure, are detected if the TxD input maintains dominant for at least t_{DOM} [1]. As a consequence the LIN transmission speed is limited to a minimum baud rate. Its calculation is shown in **Chapter 7.3**.

Furthermore if one of the above failures is present, a change of the EN input signal does not modify the TxD dominant timer state and therefore makes sure that no dominant LIN signal is driven to the bus by the TLE 7259G (fail-safe behavior).

7.3 Minimum Baud Rate and Maximum TxD Dominant Phase

Due to the TxD dominant failure detection of the TLE 7259G the maximum TxD dominant phase is limited by the minimum TxD dominant time-out time $t_{DOM, min}$ [1]. As a consequence the transmission speed is also limited to a minimum baud rate.

7.3.1 Minimum Baud Rate of a Master Node

The maximum dominant phase of the LIN protocol [2] is the maximum SYNCH BREAK LOW PHASE $T_{SYNBRK, max}$ [2] of the SYNCH BREAK FIELD. The SYNCH BREAK FIELD is part of the message frame HEADER, which is only sent by the master node. The maximum SYNCH BREAK LOW PHASE $T_{SYNBRK, max}$ [2] represents the maximum number of dominant bits sent by the master. Depending on the length of the maximum SYNCH BREAK LOW PHASE $T_{SYNBRK, max}$ [2] and the minimum TxD dominant time out time $t_{DOM, min}$ [1] the minimum baud rate for the master node can be calculated by the following equation:

$$baudrate_{\text{min, MASTER}} = \frac{T_{\text{SYNBRK, max}}}{t_{\text{DOM, min}}} \qquad \text{with } T_{\text{SYNBRK, max}} > T_{\text{SYNBRK, min}}$$

where $T_{SYNBRK, min}$ is specified in [2]

Thus the TLE 7259G allows operating within master application down to 2.4 kBaud.

7.3.2 Minimum Baud Rate of a Slave Node

A slave node sends the RESPONSE part [2] of the LIN message frame only, which has a maximum dominant phase of 9 bits (start bit + 8 data bits). As a result the minimum baud rate of a slave can be calculated by the following equation:

$$baudrate_{\mathrm{min,\,SLAVE}} = \frac{9 + n_{\mathrm{safe}}}{t_{\mathrm{DOM,\,min}}}$$

with n_{safe} as safety margin

Thus the TLE 7259G allows operating within slave application down to 1.8 kBaud.

8 Power Consumption

During design of the TLE 7259G special care has been taken on system power consumption since this is a key requirement for introduction of this new LIN sub bus system within automotive applications. The TLE 7259G achieves lowest power consumption not only within a failure free system but also during bus failure situations on the LIN bus line.

Even with the extremely low system power consumption the TLE 7259G provides full wake-up capability via the LIN bus as well as via local events keeping a high immunity against electromagnetic disturbances.

8.1 Sleep Mode Power Consumption

The TLE 7259G provides very low power consumption in sleep mode. If the transceiver is used to control the ECU supply via INH pin the only remaining system current flows into the BAT pin ($I_{BAT;\ sleep}$ **[1]**). All other pins do not sink or source any extra current (see **Figure 36**).

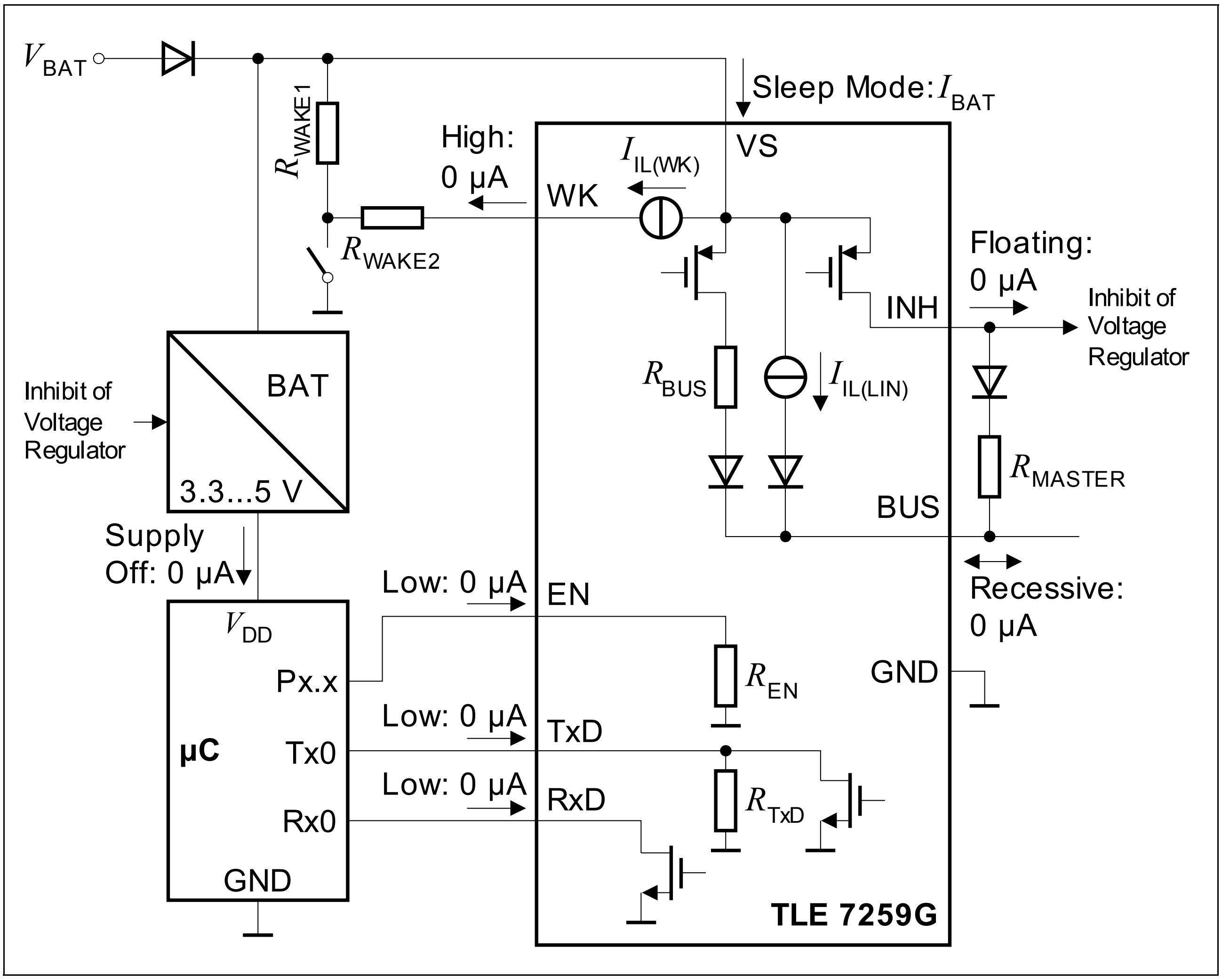


Figure 36 Current Consumption in Sleep Mode

8.2 Sleep Mode Power Consumption at Presence of LIN Bus Short-Circuit

In case of a LIN short-circuit to ground (so permanent dominant) the power consumption of the TLE 7259G keeps also very low if the sleep mode is selected. Since the termination of the system becomes nearly disabled during sleep, the resulting short-circuit current is defined by the internal bias current and the remaining pull-up current source for failure recovery (see **Figure 37**).

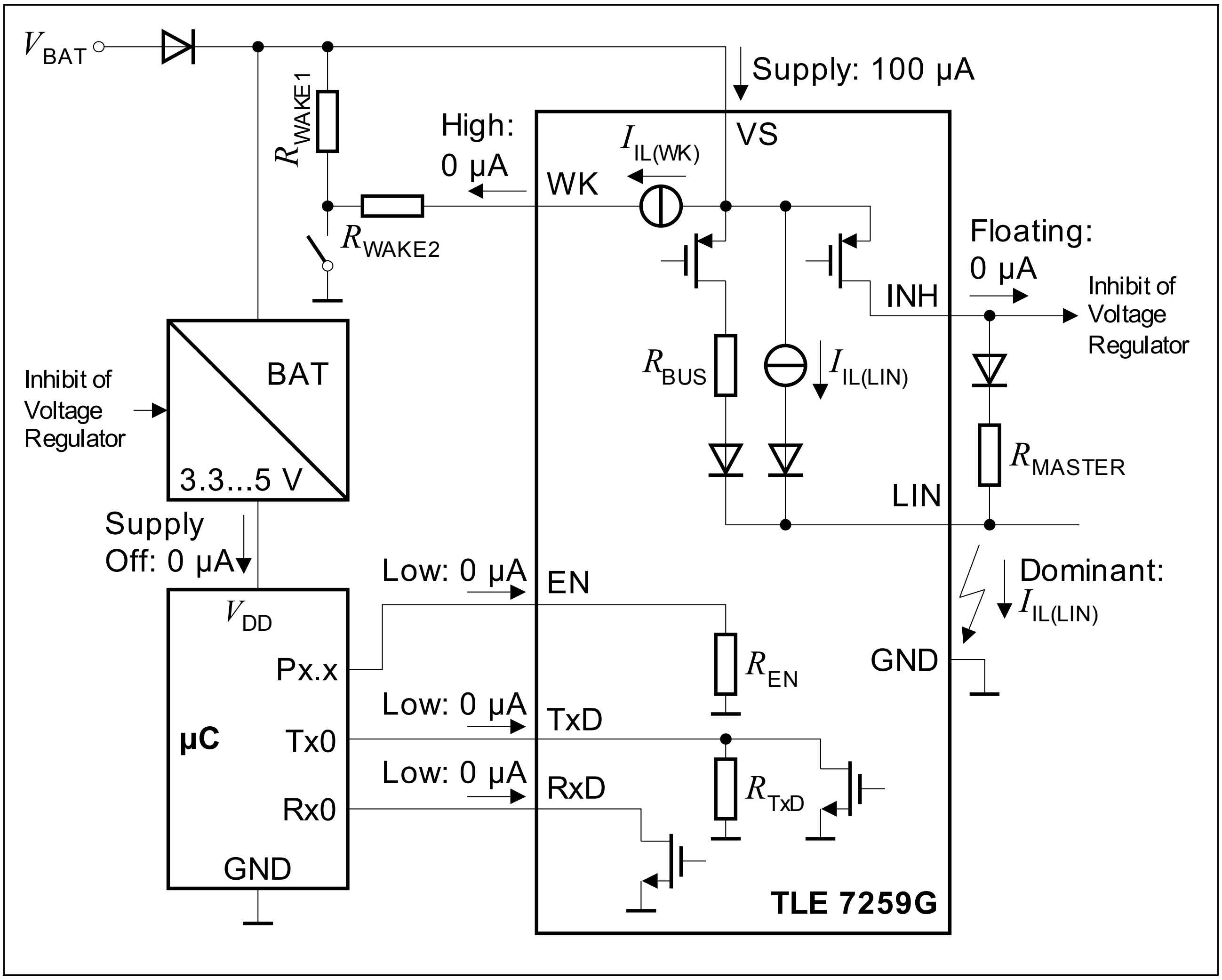


Figure 37 Typical Short-Circuit Current Consumption in Sleep Mode

9 References

[1] Data Sheet TLE 7259G, LIN Transceiver, Infineon Technologies AG - Version 1.3, 13.12.2004

[2] LIN Specification Package, LIN Protocol Specification - Revision 2.0, LIN Consortium, Nov. 2000

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

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