Preliminary
APPLICATION NOTE

TJA1020
LIN Transceiver

AN00093

Philips
Semiconductors

Abstract

The TJA1020 is a low power LIN transceiver for the use in automotive and industrial applications. It supports the single wire bus signal representation being described in the LIN protocol specification for in-vehicle Class-A buses with a single master node and a set of slave nodes. Local Interconnect Network (LIN) is a serial bus protocol being primarily intended for transmission of control related data between a number of bus nodes.

This application note provides information how to use the TJA1020 in LIN applications.

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Summary

This report provides application information for the transceiver TJA1020 from Philips Semiconductors 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 Philips LIN transceiver TJA1020 [1].

Revision History

Version	Remarks	
28.03.2001	Initial version	
04.12.2001	All Document: Chapter 2.3.2, Figure 5, Figure 7: Chapter 3.2.4.1:	- Receive Only Mode is replaced by Low Slope Mode - "Normal Mode" is renamed in "Normal Slope Mode" - Reference of C_{MASTER} and C_{SLAVE} is now ground instead of V_{BAT} - The remote wake-up behaviour via LIN bus has been changed - Wake-up after power-on
28.01.2002	Addition of document number AN00093	

Contents

1. INTRODUCTION

The Local Interconnect Network (LIN) is a low speed (max. 20kBaud) 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.

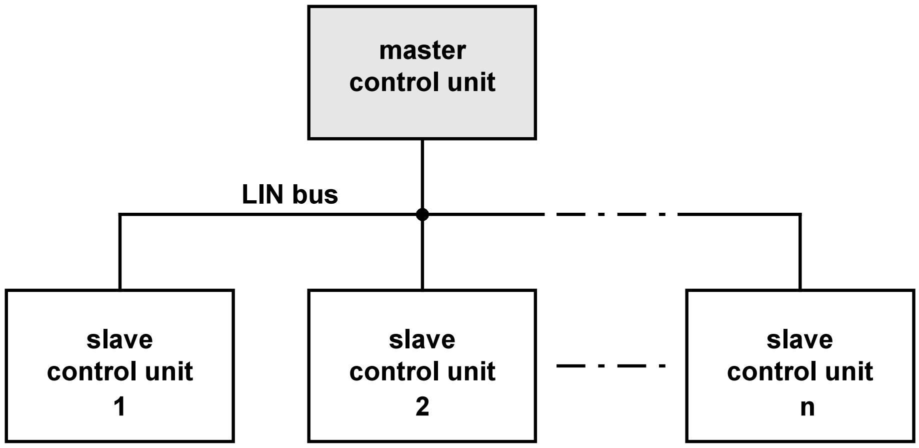


Figure 1: Single-master / multiple-slave concept

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.

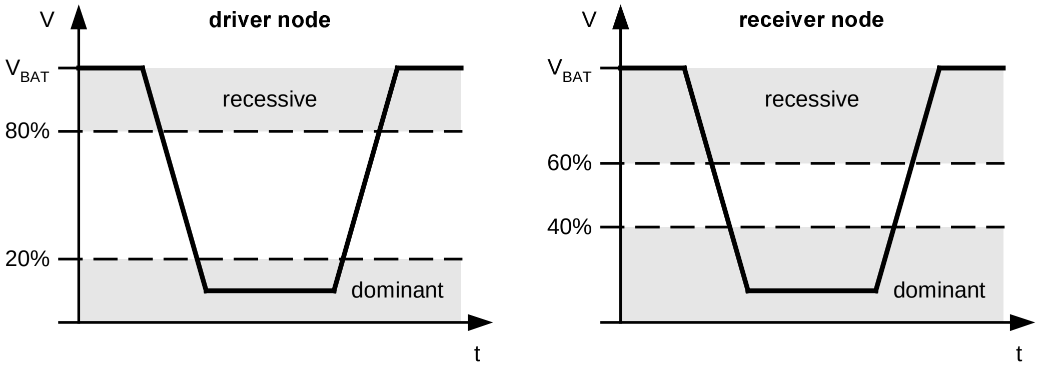


Figure 2: Voltage levels on the LIN bus line

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 12V-battery related recessive level. The voltage levels on the LIN bus line are shown in Figure 2.

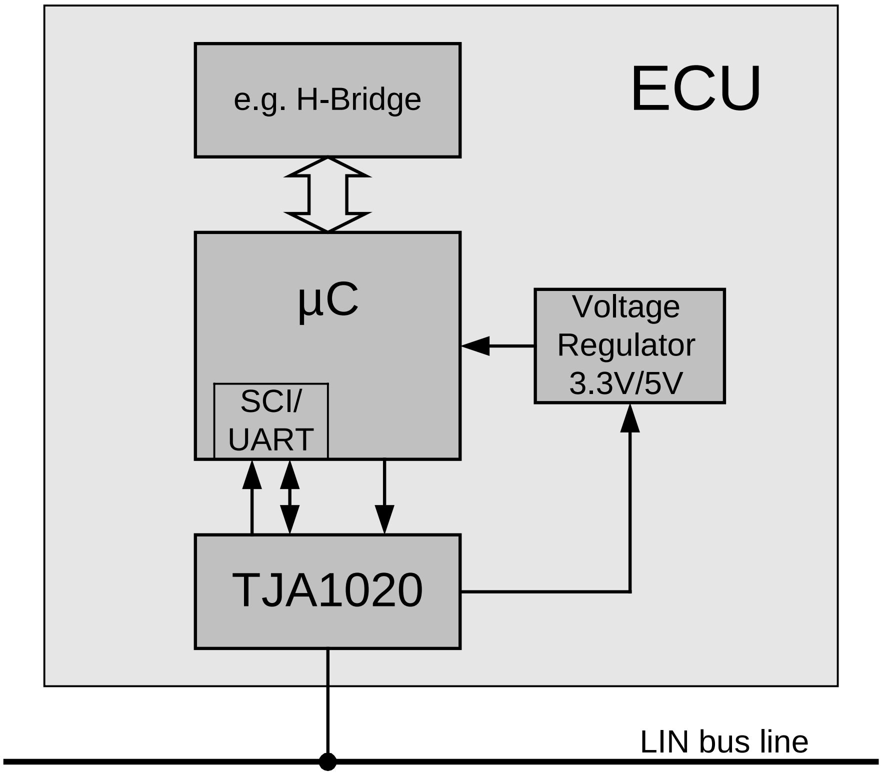


Figure 3: Typical LIN ECU

This report describes the technical implementation of the TJA1020 [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 TJA1020 from Philips Semiconductors (see Figure 3).

2. GENERAL DESCRIPTION

The transceiver TJA1020 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 controlled slew rate and wave shaping to minimize ElectroMagnetic Emission (EME). The receiver of the TJA1020 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 2.3), consumes nearly no current in sleep mode (see 8.1)and minimizes the power consumption in failure modes (see 8.2).

The TJA1020 transceiver is optimized for the maximum specified LIN transmission speed of 20kBaud and is recommended for networks including up to 16 nodes [2].

The pinning of the TJA1020 is chosen to be compatible to standard K-Line transceivers.

2.1 Features

The main features of the TJA 1020 are

- Baud rate up to 20kBaud
- Very low ElectroMagnetic Emission (EME) due to output wave shaping
- High ElectroMagnetic Immunity (EMI)
- Low Slope Mode for low speed applications (< 10kBaud) to reduce EME even further
- 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 (5V) up to jump start conditions (27V)
- Control input levels compatible with 3.3V and 5V 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 behaviour in case of 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 5V supply required
- Thermally protected

2.2 Block Diagram

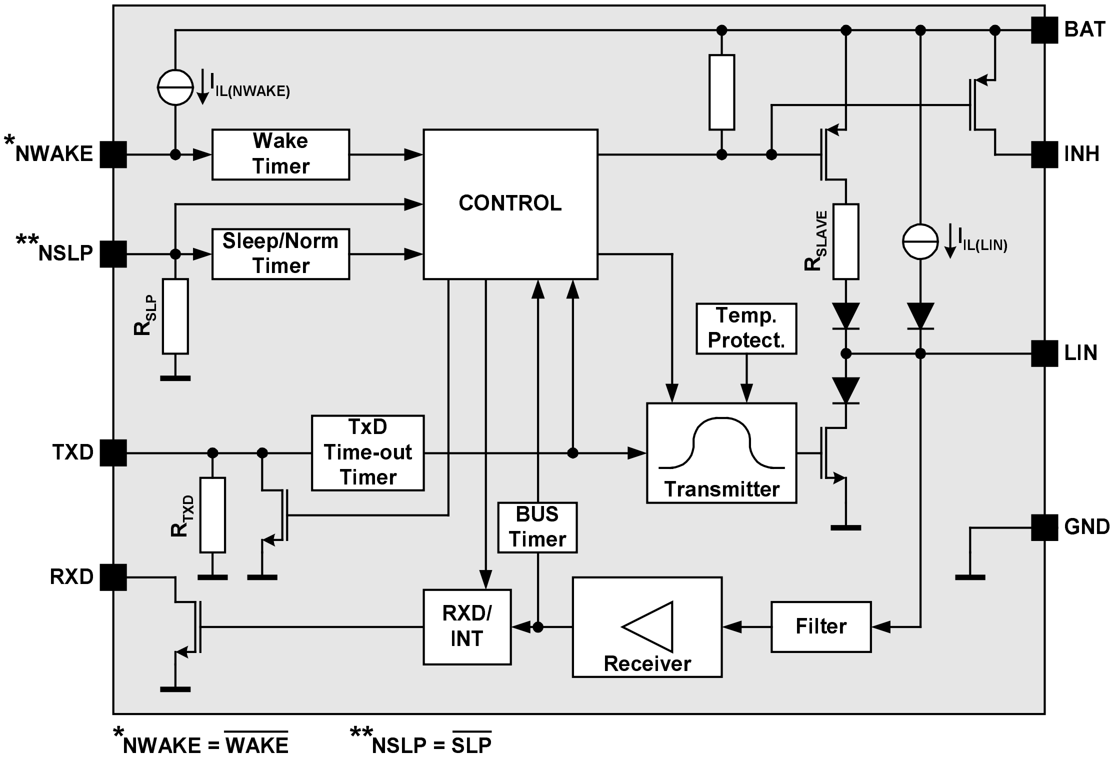


Figure 4: Block diagram of the TJA1020

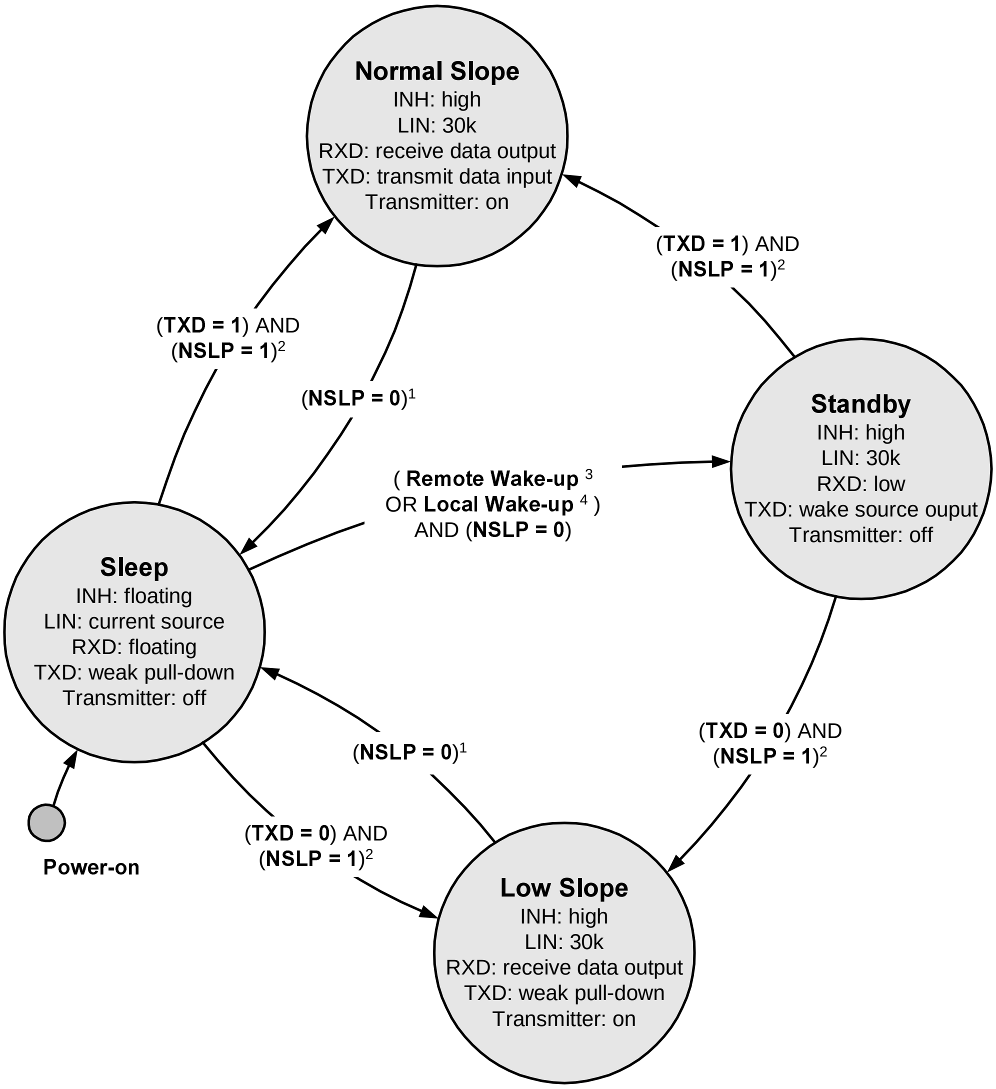
2.3 Operating Modes

The TJA1020 provides four operating modes: normal slope mode, low slope mode, standby mode and sleep mode. The operating modes are shown in Table 1 and Figure 5.

Mode	NSLP	TXD	RXD	INH	Trans-mitter	R_{SLAVE}	Remarks
Sleep	0	weak pull-down	floating	floating	off	current source	see 2.3.1
Standby	0	weak pull-down if remote wake-up; strong pull-down if local wake-up	low	high (V_{BAT})	off	30kΩ	see 2.3.2
Low Slope	1	weak pull-down	high: recessive state low: dominant state	high (V_{BAT})	on	30kΩ	see 2.3.4
Normal Slope	1	weak pull-down	high: recessive state low: dominant state	high (V_{BAT})	on	30kΩ	see 2.3.3

Table 1: Operating Modes

Figure 5 shows the state diagram of the TJA1020.



1) $t_{(NSLP=0)} > t_{gotosleep}$ [1]
2) $t_{(NSLP=1)} > t_{gotonorm}$ [1]
3) LIN becomes dominant for $t_{(LIN=0)} > t_{BUS}$ [1] and is followed by an edge to recessive
4) NWAKE becomes low for $t_{(NWAKE=0)} > t_{NWAKE}$ [1]

Figure 5: State diagram

2.3.1 Sleep Mode

The sleep mode of the TJA1020 provides the lowest achievable power consumption within LIN ECU's. 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 NWAKE will be recognised and results in a mode change towards standby mode (see 2.3.2). Furthermore the TJA1020 provides a direct activation of normal or low slope mode via NSLP (see 2.3.3 and 2.3.4) which is useful for applications where the microcontroller supply is not controlled by the INH output.

The TJA1020 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 (NWAKE) and of the sleep control input (NSLP). Therefore all wake-up events have to maintain for a certain time period (t_{BUS}, t_{WAKE}, $t_{gotonorm}$).

The sleep mode is entered if a low level at the sleep control input pin NSLP maintains for at least $t_{gotosleep}$ [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 NWAKE are clamped to ground, e.g. caused by a short-circuit to ground.

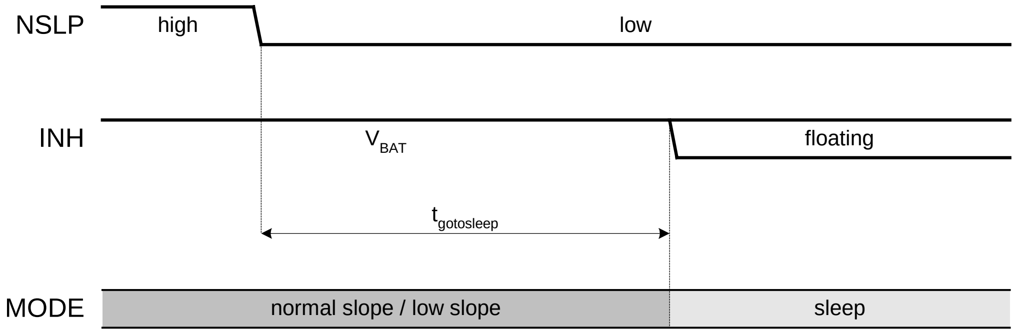


Figure 6: Sleep mode timing

During sleep mode, the internal slave termination resistor R_{SLAVE} 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 TJA1020 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_{SLAVE} between LIN and BAT is activated.

The TJA1020 signals the standby mode with a low level at the RXD pin. This can be used as wake-up interrupt request for a microcontroller. 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 microcontroller an external pull-up resistor could be necessary (see 3.2.2).

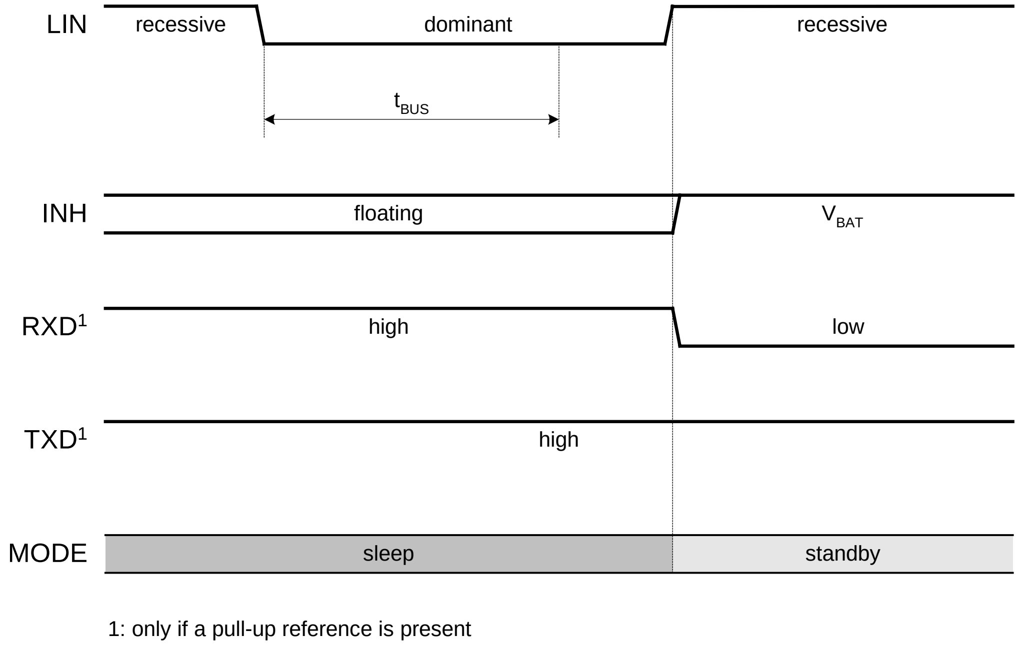


Figure 7: Standby mode timing of remote wake-up

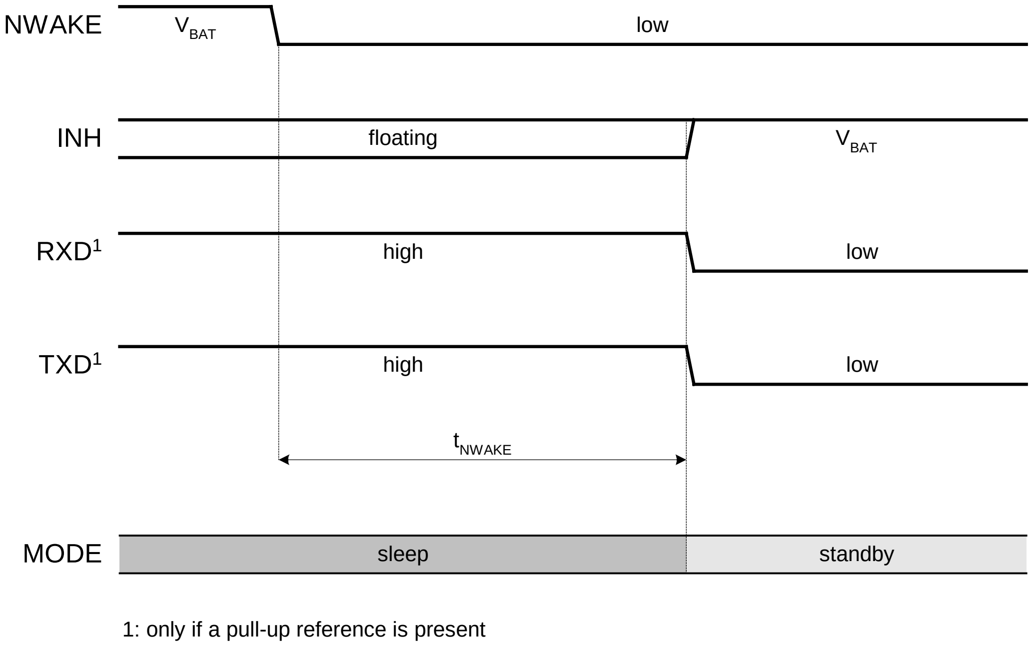


Figure 8: Standby mode timing of local wake-up

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_{BUS} [1] followed by an edge to recessive bus level. A falling edge at the NWAKE pin results in a local wake-up if the low level maintains for at least t_{NWAKE} [1].

2.3.3 Normal Slope Mode

The normal slope 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 microcontroller. 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 TJA1020 converts the data stream of the microcontroller 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 slope mode the internal slave termination resistor R_{SLAVE} [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 slope mode is entered setting NSLP and TXD high for at least $t_{gotonorm,max}$ [1]. The mode transition is executed when $t_{gotonorm}$ [1] is expired. Figure 9 shows the timing of a transition from sleep or standby mode to normal slope mode.

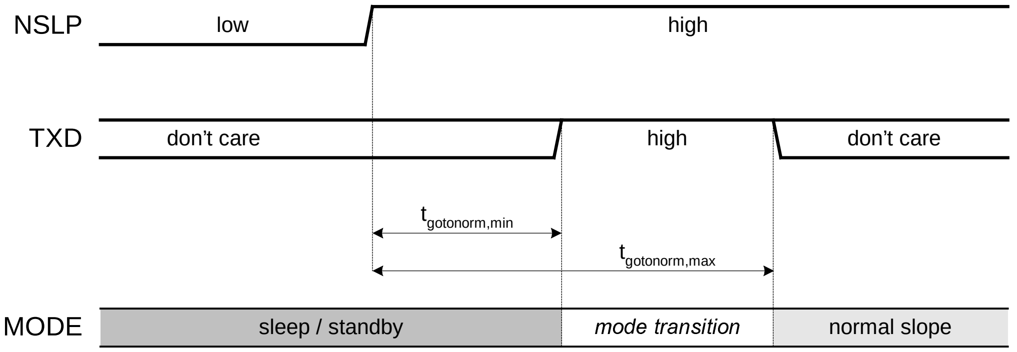


Figure 9: Normal slope mode timing

2.3.4 Low Slope Mode

The low slope mode can be used within LIN systems below 10kBaud and allows a further reduction of the EME compared to the already very low EME of the normal slope mode. So the only difference compared to normal slope mode is the bus signal transition time. For the low slope mode, the transition time is about two times longer than for the normal slope mode (see Figure 10).

The low slope mode can be entered only coming from the sleep or standby mode. A direct transition from normal slope to low slope mode is not possible.

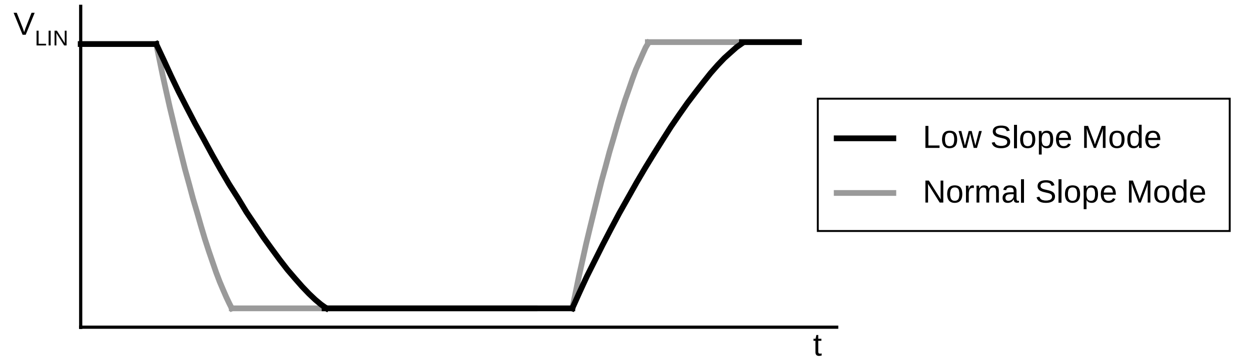


Figure 10: Reduced LIN bus slope in low slope mode

The low slope mode is entered by a low level on the TXD pin in conjunction with a high level on the NSLP pin maintained for at least $t_{gotonorm,max}$ [1]. The mode transition is executed when $t_{gotonorm}$ [1] is expired. The timing of a transition from sleep or standby mode to low slope mode is shown in Figure 11.

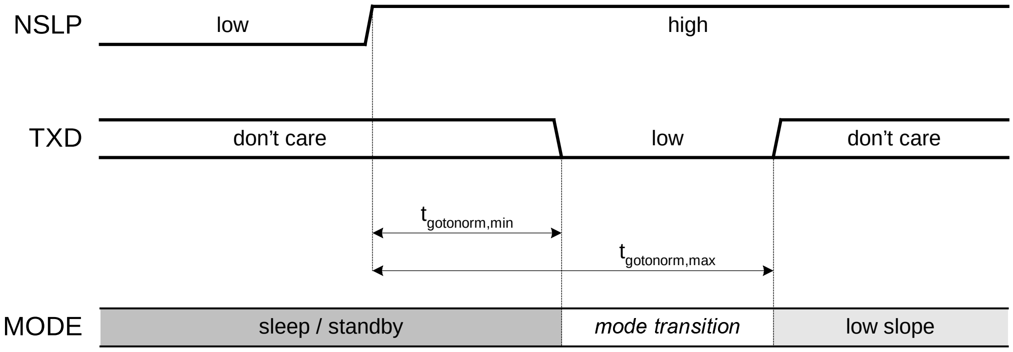


Figure 11: Low slope mode timing

2.4 Compatibility With 3.3V Devices

The TJA1020 is designed to support the increasing demand for lower supply voltages than 5V within automotive applications. It provides reduced input thresholds at the input pins TXD and NSLP and open drains at the output pins RXD and TXD. So it is compatible to 3.3V supplied microcontroller as well as to 5V supplied devices. There is no 5V tolerant behaviour of interface pins between the TJA1020 and the host microcontroller needed and furthermore no extra VCC 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 microcontroller port pin itself.

3. SLAVE APPLICATION

3.1 Set-up

A slave application of the LIN transceiver TJA1020 is shown in Figure 12. The protocol controller (e.g. microcontroller) is connected to the LIN transceiver via a UART/SCI based interface or standard I/O port pins. The TXD pin of the TJA1020 is the transmit data input and the RXD pin is the receive data output. The sleep control input NSLP of the LIN transceiver can be controlled by a microcontroller port pin. The TJA1020 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 12 is recommended in order to improve the EME as well as EMI performance of the LIN system (see also chapter 5).

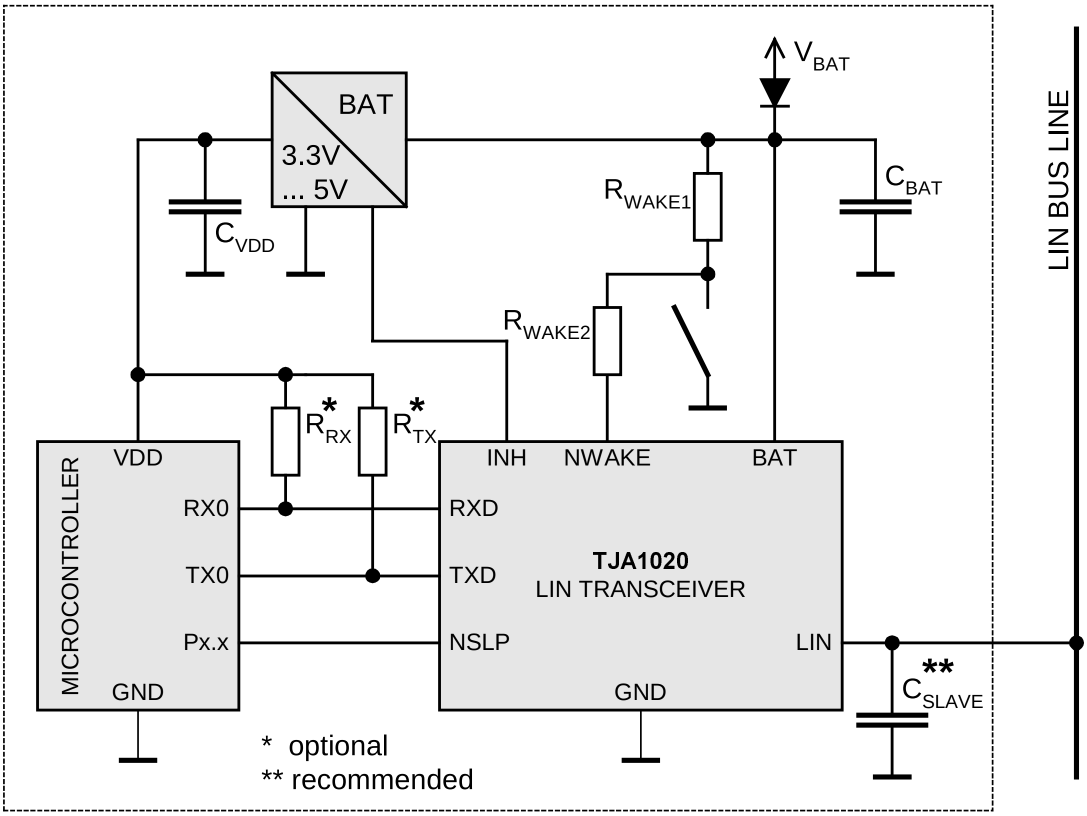


Figure 12: TJA1020 application example

3.2 Detailed Pin Description

3.2.1 NSLP Pin

The sleep control pin NSLP provides an internal pull-down resistor R_{SLP} to support a defined input level in case of open circuit failures. A low level results in the sleep mode and reduces the power dissipation to a minimum. The range of the input threshold is chosen to support 5V as well as 3.3V supplied devices. A typical NSLP pin application is shown in Figure 13.

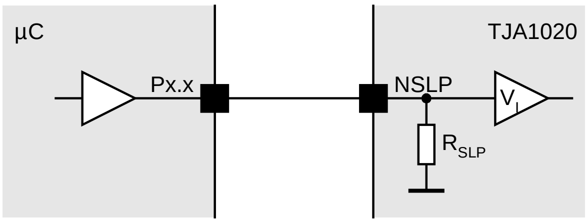


Figure 13: Typical NSLP pin application

The minimum drive capability of the microcontroller port pin for the NSLP pin can be calculated with the following equation:

Min. high level port pin strength @ $V_{uC} > V_{IH(SLP),min}$:

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

with [1]

$V_{IH(SLP),min}$	minimum NSLP HIGH-level input voltage
$R_{SLP,min}$	minimum NSLP pull-down resistor
$I_{IL(SLP),max}$	maximum NSLP 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 slope and low slope 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 NWAKE pin. If a local wake-up source at the NWAKE pin is used, a pull-up behaviour at pin TXD is required. This pull-up can be achieved in two ways:

a) The microcontroller port pin provides an integrated pull-up $R_{TX(uC)}$ (see Figure 14a).

b) An external pull-up resistor $R_{TX(ext)}$ towards the local VCC is connected (see Figure 14b).

In case no local wake-up source is present (NWAKE is unused), no external pull-up resistor is required. Then TXD will never be pulled to a strong low level by the TJA1020.

If the local wake-up feature of the TJA1020 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 TJA1020.

The required strength of the microcontroller 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 @ $V_{TX(uC)} > V_{IH(TXD),min}$:

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

Max. low level pull-up current @ $V_{TX(uC)} < V_{IL(TXD),max}$:

$$I_{LOW(RTX),\max} = \frac{V_{IL(TXD),\max}}{V_{TXD}} I_{OL(TXD),\min} \qquad \text{with } V_{TXD} = 0.4V$$

Range of pull-up resistor:

$$R_{TX,\min} < R_{TX} < R_{TX,\max} \qquad \text{with}$$

$$R_{TX,\min} = \frac{VCC_{\max} - V_{IL(TXD),\max}}{I_{LOW(RTX),\max}} \text{ and } R_{TX,\max} = \frac{VCC_{\min} - V_{IH(TXD),\min}}{I_{HIGH(RTX),\min}}$$

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

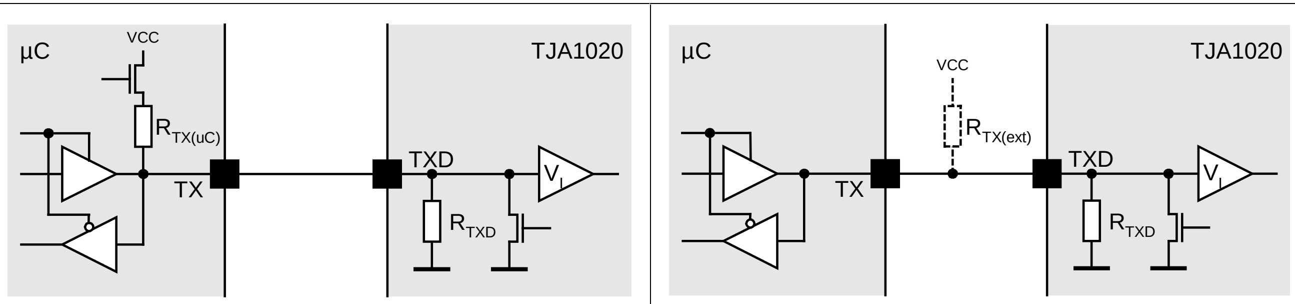
Note: For LIN the signal symmetry of the falling and rising transition on TXD has an impact on the overall system tolerances. Thus it is recommended to keep the RC-load time constant on the TXD input as small as possible.

Example: If the supply voltage of the microcontroller ($VCC=VCC_{min}=VCC_{max}$) is 5V, then the range of the pull-up resistor R_{TX} is:

$$R_{TX,\min} = \frac{VCC_{\max} - V_{IL(TXD),\max}}{I_{LOW(RTX),\max}} = 1.4k\Omega \qquad \text{with } I_{LOW(RTX),\max} = \frac{V_{IL(TXD),\max}}{V_{TXD}} I_{OL(TXD),\min} = 3mA$$

$$R_{TX,\max} = \frac{VCC_{\min} - V_{IH(TXD),\min}}{I_{HIGH(RTX),\min}} \approx 140k\Omega \qquad \text{with } I_{HIGH(RTX),\min} = \frac{V_{IH(TXD),\min}}{R_{TXD,\min}} + I_{IL(TXD),\max} = 21\mu A$$

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



a) for µC with internal programmable pull-up

b) for µC without internal pull-up

Figure 14: 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 3.3V as well as 5V microcontroller derivatives. Thus 3.3V microcontroller derivatives without 5V tolerant ports can be used for the TJA1020.

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 behaviour in order to get an output level, which can be adapted to the microcontroller supply voltage. Thus 3.3V microcontroller derivatives without 5V tolerant ports can be used. In case the microcontroller port pin does not provide an integrated pull-up, an external pull-up resistor connected to the microcontroller supply voltage VCC is required. In Figure 15 typical RXD applications are shown.

The pull-up resistor R_{RX} is defined by the drive capability of the TJA1020's RXD output pin and can be calculated by the equations below:

Range of pull-up resistor:

$$R_{RX,\min} < R_{RX} < R_{RX,\max} \qquad \text{with}$$

$$R_{RX,\min} = \frac{VCC_{\max} - V_{L\quad(RX),\max}}{V_{L\quad(RX),\max}} \cdot \frac{V_{RXD}}{I_{L\ (RXD),\min}}, \qquad V_{RXD} = 0.4V \quad \text{and}$$

$$R_{RX,\max} = \frac{VCC_{\min} - V_{HIGH(RX),\min}}{I_{LH(RXD),\max}}$$

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

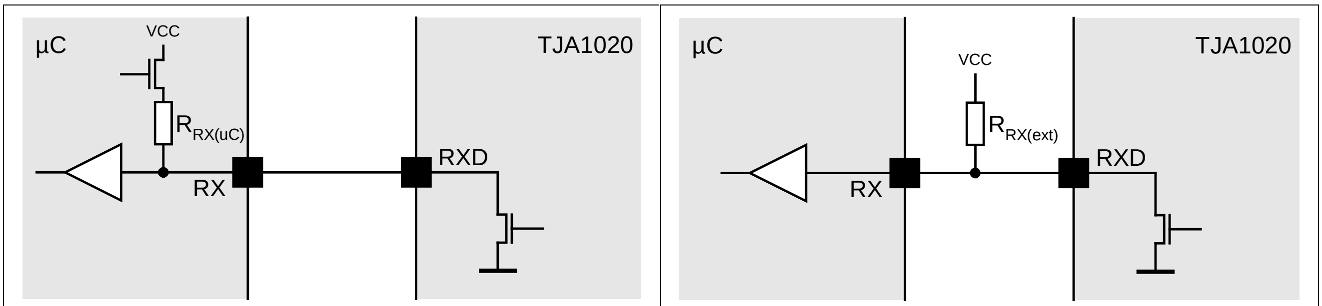
Note: For LIN the signal symmetry of the falling and rising transition on RXD has an impact on the overall system tolerances. Thus it is recommended to keep the RC-load time constant on the RXD output as small as possible, but the pull-up resistor R_{RX} should not be below 1kΩ.

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

$$R_{RX,\min} = \frac{VCC_{\max} - V_{LOW(RX),\max}}{V_{LOW(RX),\max}} \cdot \frac{V_{RXD}}{I_{OL(RXD),\min}} = 1.4k\Omega$$

$$R_{RX,\max} = \frac{VCC_{\min} - V_{\quad(RX),\min}}{I_{L\ (RXD),\max}} \approx 600k\Omega$$

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



a) for µC with internal programmable pull-up

b) for µC without internal pull-up

Figure 15: Typical RXD pin application

3.2.4 NWAKE Pin

The local wake-up input NWAKE 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_{NWAKE} in order to guarantee an optimum EMI filtering behaviour. The NWAKE pin provides an internal weak pull-up current source $I_{IL(NWAKE)}$ [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 NWAKE has a different ground path than the TJA1020, it is recommended to add a series resistor R_{WAKE2} between the NWAKE pin and the wake-up source. If the ECU has lost its ground while the wake-up source is still connected to ground, the series resistor R_{WAKE2} protects the ECU against a reverse current supply through the internal protection diodes of NWAKE. Figure 16a shows a typical NWAKE 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:

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

$$R_{WAKE2,\min} = \frac{V_{BAT,\max}}{I_{NWAKE,\min}} \qquad \text{and}$$

$$R_{WAKE2,\max} = \frac{V_{IL(NWAKE),\max} - |V_{GND-shift}|}{I_{IL(NWAKE),\min}} \qquad \text{with e.g. } V_{GND-shift} = 1.5V$$

with [1]

$V_{IL(NWAKE),max}$	maximum NWAKE LOW-level input voltage
$I_{IL(NWAKE),min}$	minimum NWAKE pull-up current
$I_{NWAKE,min}$	minimum NWAKE output current (Limiting Value)

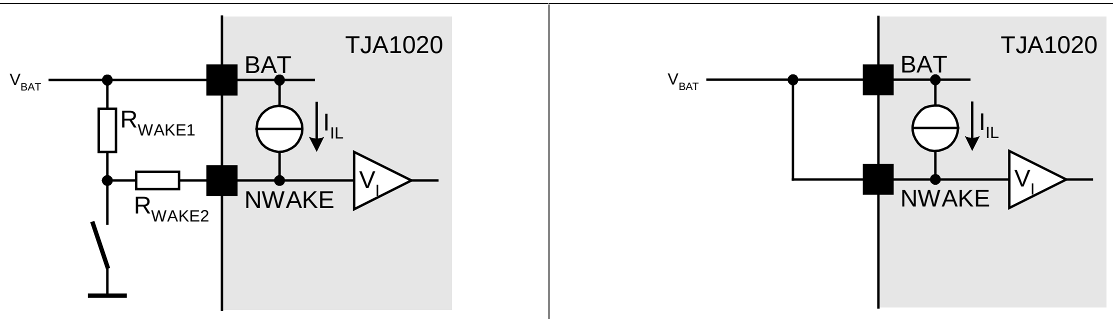
Example: For a maximum ground-shift of $V_{GND\text{-}shift} = 1.5V$ and a battery voltage range of $V_{BAT} = 5\ldots27V$ is the range of R_{WAKE2}:

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

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

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

If no local wake-up is required for the application the NWAKE pin can be left open, due to the internal pull-up and filter behaviour. Nevertheless it is recommended to connect the NWAKE pin directly to the BAT pin (see Figure 16b) if not used.



a) for local wake-up via external switch

b) for applications without local wake-up

Figure 16: Typical NWAKE pin application

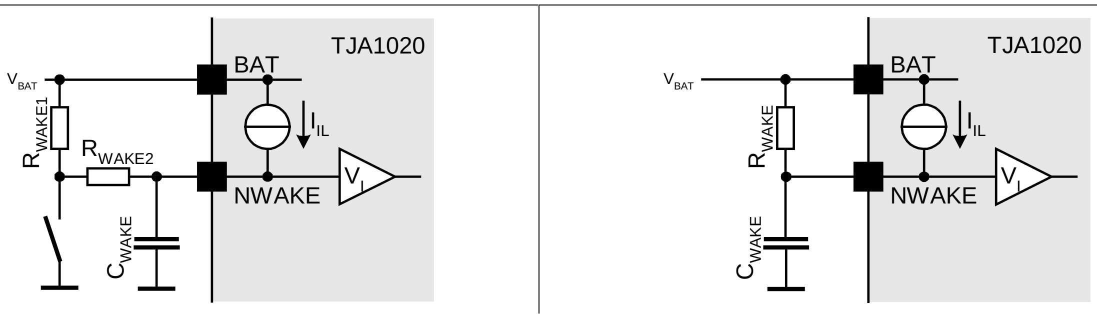
The TJA1020 provides also hardware compatibility to other LIN transceiver implementations, which have a VCC supply input instead of a local wake-up input at pin 3. Therefore the wake-up threshold of the NWAKE input is defined to be above 5V. Thus this pin can be connected to the applications VCC supply without forcing a wake-up event in case VCC drops down (e.g. system sleep mode). Nevertheless this would cause a small extra current consumption $I_{IL(NWAKE)}$ [1] (internal weak current source) of the system.

3.2.4.1 Wake-up after Power-on

After power-on the TJA1020 enters directly the sleep mode keeping INH on floating condition and thus the supply of the LIN node disabled. This behaviour reduces the total power-on peak current of a LIN sub-system.

Nevertheless in some applications a LIN node needs to be waked up autonomously after powering up. This can be achieved with a RC-combination on NWAKE (see Figure 17b). During power-on such an RC-combination can generate a local wake-up by keeping the NWAKE input voltage V_{NWAKE} below $V_{IL(NWAKE),max}$ [1] for at least $t_{NWAKE,max}$ [1].

The circuit in Figure 17a provides a solution for both, a local wake-up via external switch and an autonomous wake-up after power-on. For the calculation of R_{WAKE1} and R_{WAKE2} see above.



a) for local wake-up via external switch

b) for applications without local wake-up

Figure 17: Typical NWAKE pin application to wake-up after power-on

Figure 18 shows the relation between the battery voltage V_{BAT} and the resulting NWAKE voltage V_{NWAKE} during power-on, and it shows its constraints to wake-up the TJA1020. The RC-combination can be calculated by the following rule:

RC time constant to wake-up after power-on:

$$R_{WAKE}\,C_{WAKE} = t_{BAT-ON,\max} > 2\,t_{NWAKE,\max}$$

with

$t_{NWAKE,max}$	maximum dominant time to wake-up via NWAKE [1]
$t_{BAT-ON,max}$	maximum power-on ramp-up time of V_{BAT}

Example: Assuming the maximum power-on ramp-up time $t_{BAT-ON,max}$ is 1ms and the pull-up resistor R_{WAKE} should be 10kΩ, then C_{WAKE} is:

$$C_{WAKE} = \frac{t_{BAT-ON,\max}}{R_{WAKE}} = 100nF \qquad \text{with} \quad t_{BAT-ON,\max} = 1ms \quad > \quad 2\,t_{NWAKE,\max} = 100\mu s$$

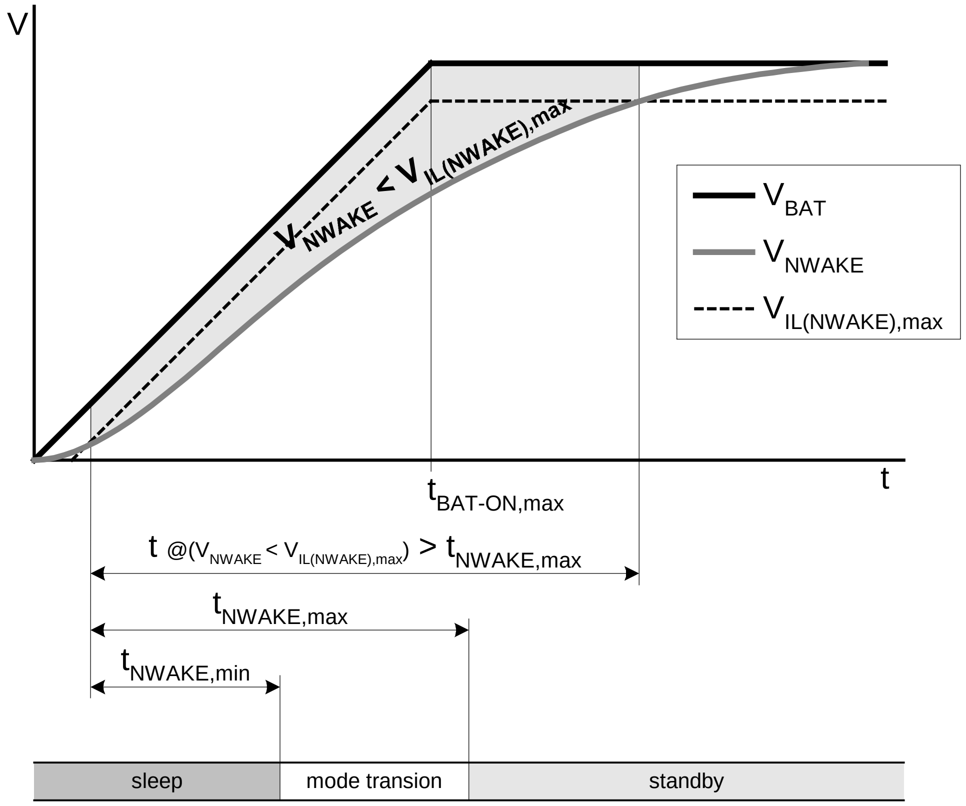
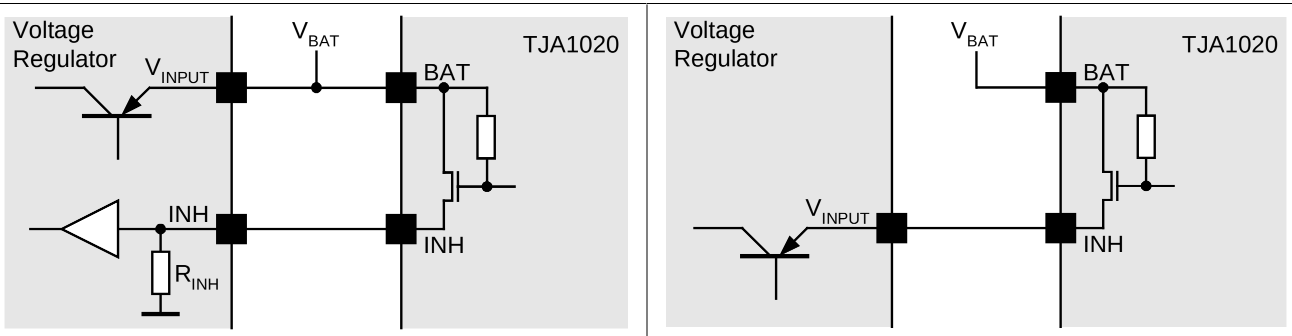


Figure 18: Timing to wake-up after power-on

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 19a.



a) for voltage regulators with inhibit input

b) for voltage regulators without inhibit input

Figure 19: 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 3.2.5.2

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

with

$I_{LH(INH),max}$	maximum INH HIGH-level leakage current [1]
$V_{LOW(VoltReg),max}$	maximum inhibit LOW-level input voltage (volt regulator)

3.2.5.2 Direct Voltage Regulator Supply

Due to the INH drive capability, the TJA1020 is able to supply a voltage regulator directly. Figure 19b 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:

$$I_{INH,\max} = \sqrt{\frac{P_{\max} - P_{Q,\max} - P_{TX,\max}}{R_{SW(INH),\max}}} \quad \text{with} \quad I_{INH,\max} \leq 50mA$$

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

Max. voltage drop at INH:

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

with

$P_{Q,max}$	maximum quiescence power dissipation (normal slope mode, bus recessive, $V_{INH} = V_{BAT}$), see Figure 20
$P_{TX,max}$	maximum transmitter power dissipation (normal slope mode, transmission duty cycle = 50%, $V_{INH} = V_{BAT}$), see Figure 20
$R_{SW(INH),max}$	maximum switch-on resistance between BAT and INH [1]

and

$T_{vj,max}$	maximum virtual junction temperature (K) [1]
$T_{amb,max}$	maximum ambient temperature (K)
$R_{th(j-a)}$	thermal resistance (K/W) [1]

Note: Independently from the above calculation the current through the INH pin I_{INH} should not exceed 50mA.

The power dissipation depends on the supply voltage V_{BAT} and the baud rate. Figure 20 shows the quiescence power dissipation P_Q and the transmitter power dissipation P_{TX} of the TJA1020 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=10nF) are used for the transmitter power dissipation P_{TX} in Figure 20.

The thermal resistance $R_{th(j-a)}$ [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 $I_{INH,max}$.

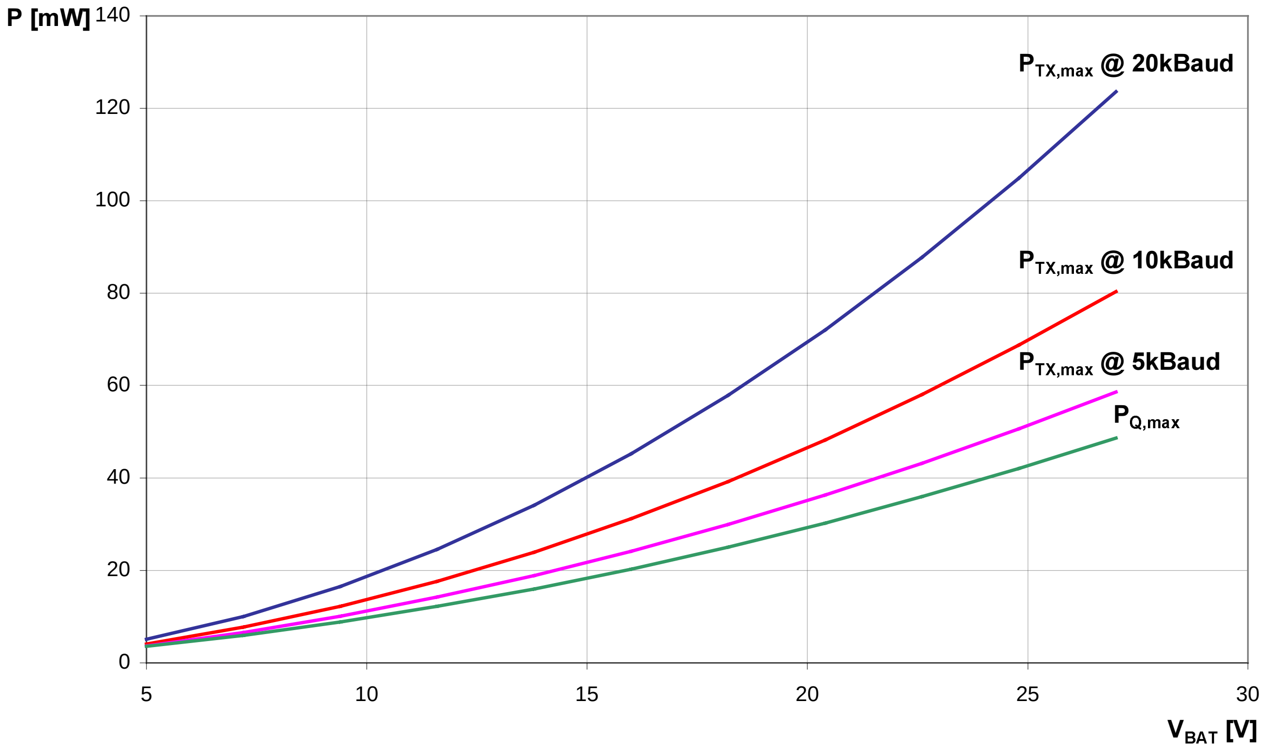


Figure 20: Power dissipation in normal slope mode

3.2.6 LIN Pin

The pin LIN is used to transmit and receive data on the LIN bus line. The transmission is performed by a low side switch with controlled wave shaping, and the reception is undertaken by an implemented receiver. The threshold of the receiver $V_{th(rx)}$ [1] is battery related and has a hysteresis of $V_{thr(hys)}$ [1].

The LIN pin has a weak pull-up current source of $I_{IL(LIN)}$ [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 21). 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 12.

The current source of $I_{IL(LIN)}$ [1] is used as an additional weak pull-up, because the slave termination resistor R_{SLAVE} [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 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 TJA1020 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 21.

Such a master application solution does not provide fail-safe system behaviour 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.

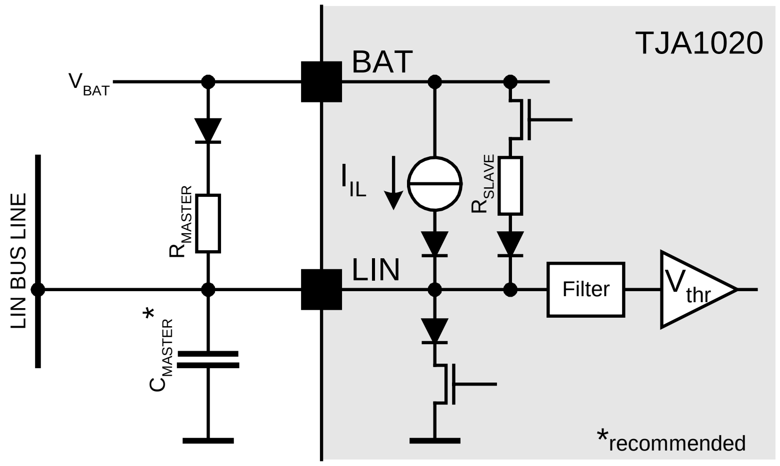


Figure 21: Typical master termination

4.2 Master Termination towards INH

For fail-safe reasons the TJA1020 supports an advanced master application solution using the INH pin to drive the master termination resistor R_{MASTER} [2]. As shown in Figure 22 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 microcontroller detects a permanent dominant level on the LIN bus line caused by a ground short-circuit, the microcontroller 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_{SLAVE} [1]. Only the internal weak pull-up current source $I_{IL(LIN)}$ [1] and the internal current consumption of the TJA1020 determine the remaining current consumption of a LIN node in such a failure case (see also 8.2).

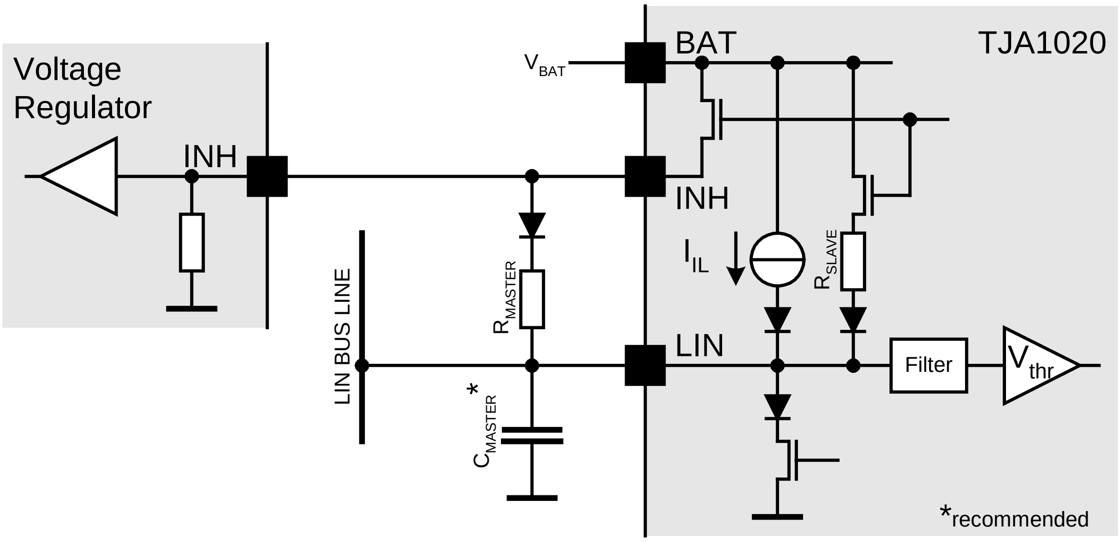


Figure 22: Advanced master termination through the INH pin

4.3 Master Termination Split between INH and BAT

Since the advanced master termination in chapter 4.2 provides a fail-safe system behaviour 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 23).

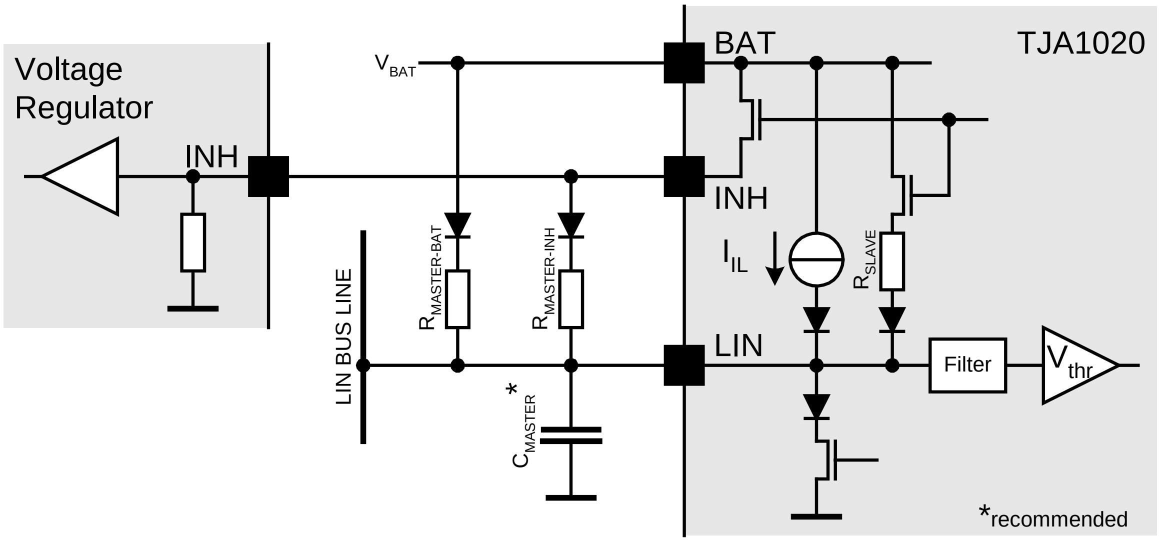


Figure 23: Trimmed master termination

The resistors $R_{MASTER\text{-}BAT}$ and $R_{MASTER\text{-}INH}$ in parallel determine the master termination while the TJA1020 is in its modes: standby, normal slope and low slope. In sleep mode the master termination is determined by $R_{MASTER\text{-}BAT}$. Therefore the maximum LIN bus short-circuit current $I_{SC,max}$ can be trimmed by $R_{MASTER\text{-}BAT}$:

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

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

5. EMC ASPECTS

5.1 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 ElectroMagnetic 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 TJA1020 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 ($C_{BUS} = C_{MASTER} + n * C_{SLAVE} * C_{LINE}$ [2]) can further reduce the EME. For very high bit rates close to 20kBaud 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.

5.2 EME – Low Slope Mode

The curve shaping of the LIN bus signal in normal slope mode is optimised for the maximum specified LIN transmission speed of 20kBaud. Thus for low speed LIN applications (e.g. 4.8kBaud) the curve shaping in normal slope mode has unnecessary steep slopes. Therefore the TJA1020 provides the low slope mode (see 2.3.4) with reduced slopes (see Figure 10). These reduced slopes result in a further reduction of EME and they are optimised for LIN applications with transmission speeds below 10kbaud.

5.3 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. $C_{MASTER/SLAVE} = 220pF$) from LIN to ground at each node.

6. TRANSCEIVER CONTROL

The modes of the TJA1020 are controlled by the pins NSLP and TXD. The following chapters describe the mode control of TJA1020 and how to deal with LIN bus failures.

The transceiver control can be split into two basic applications:

- the microcontroller power supply is controlled via the INH pin of the TJA1020,
- independent of the TJA1020's modes the microcontroller is permanently supplied.

6.1 INH controlled Microcontroller 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 microcontroller becomes supplied and starts with its initialisation. The TJA1020 indicates the wake-up event by an active low at RXD.

Depending on the use of the NWAKE pin two different software-flows for mode control are recommended:

6.1.1 Applications using NWAKE

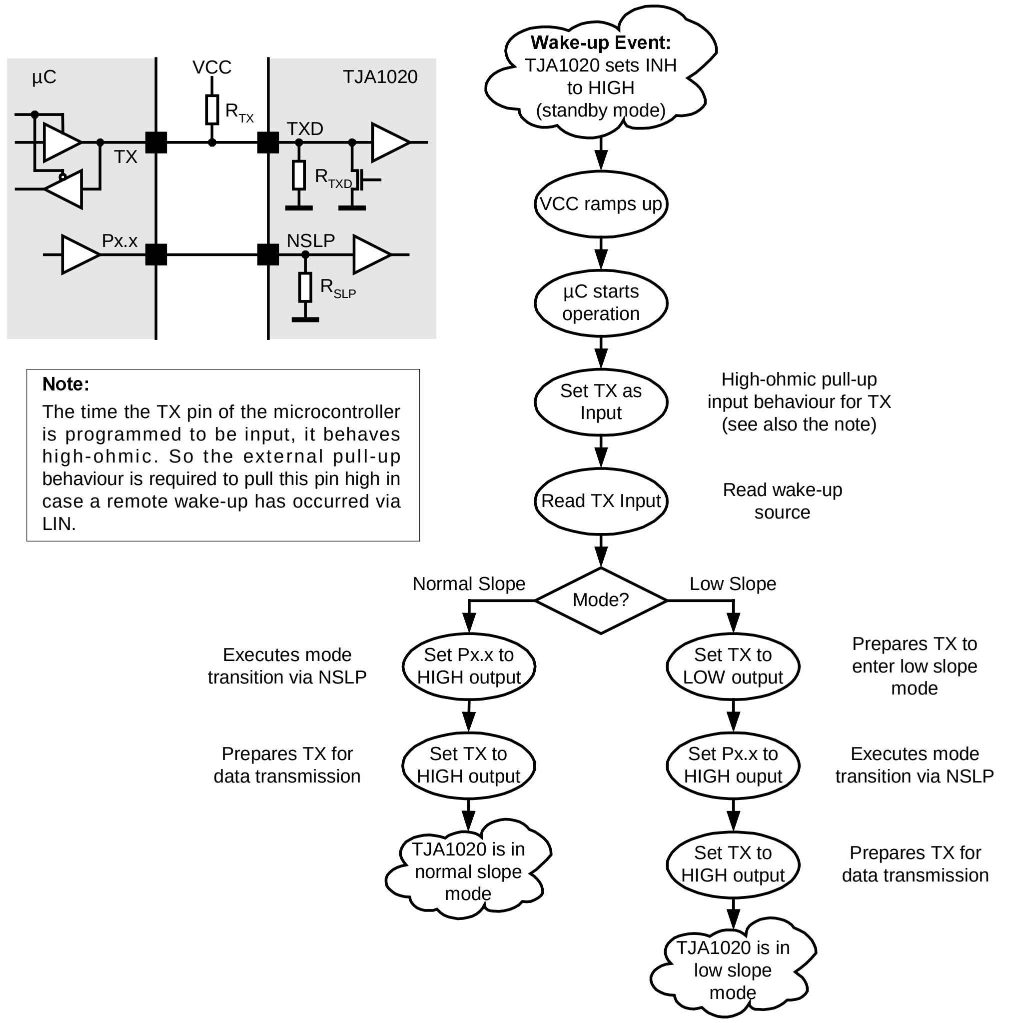
The TJA1020 allows distinguishing between different wake-up sources using the TXD pin. Thus the TXD pin needs to be applied with a pull-up behaviour as described in chapter 3.2.2. This pull-up behaviour is required to sense the TJA1020's pull-down transistor at TXD, which becomes active after a local wake-up event via NWAKE. Thus the wake-up source can be distinguished by reading the TJA1020's TXD pin.

To distinguish between normal slope mode and low slope mode the TJA1020's TXD pin is used. The normal slope mode is entered if TXD carries a high level after NSLP is set high. TXD gets high automatically after a local wake-up event if the corresponding microcontroller port pin is configured to be input (weak high) because the wake-up source information is cleared immediately with setting NSLP to high level. The mode change itself is performed holding NSLP high for at least $t_{gotonorm}$ [1] (see also the timing in Figure 9).

Note: There is no software timing constraint required for setting the microcontroller port pin TX to high output after setting NSLP to high, because the local wake-up source information at TXD is cleared immediately with setting NSLP to high level, whereas the mode transition itself executes after $t_{gotonorm}$ [1].

To enter the low slope mode the microcontroller TX port pin is simply set low before the NSLP input pin of the TJA1020 gets a high level.

Figure 24 shows the related software flow of a standby to normal/low slope 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 24: Flow diagram of standby to normal/low slope transition, using NWAKE

6.1.2 Applications without using NWAKE

In case no local wake-up source is present the hardware becomes simpler because the TXD pin of the TJA1020 behaves as input only. Thus the weak pull-up behaviour as described in chapter 6.1.1 is not required.

The software flow is shown within Figure 25. Here the TXD input of the TJA1020 defines the next mode before the NSLP input is set to a high level.

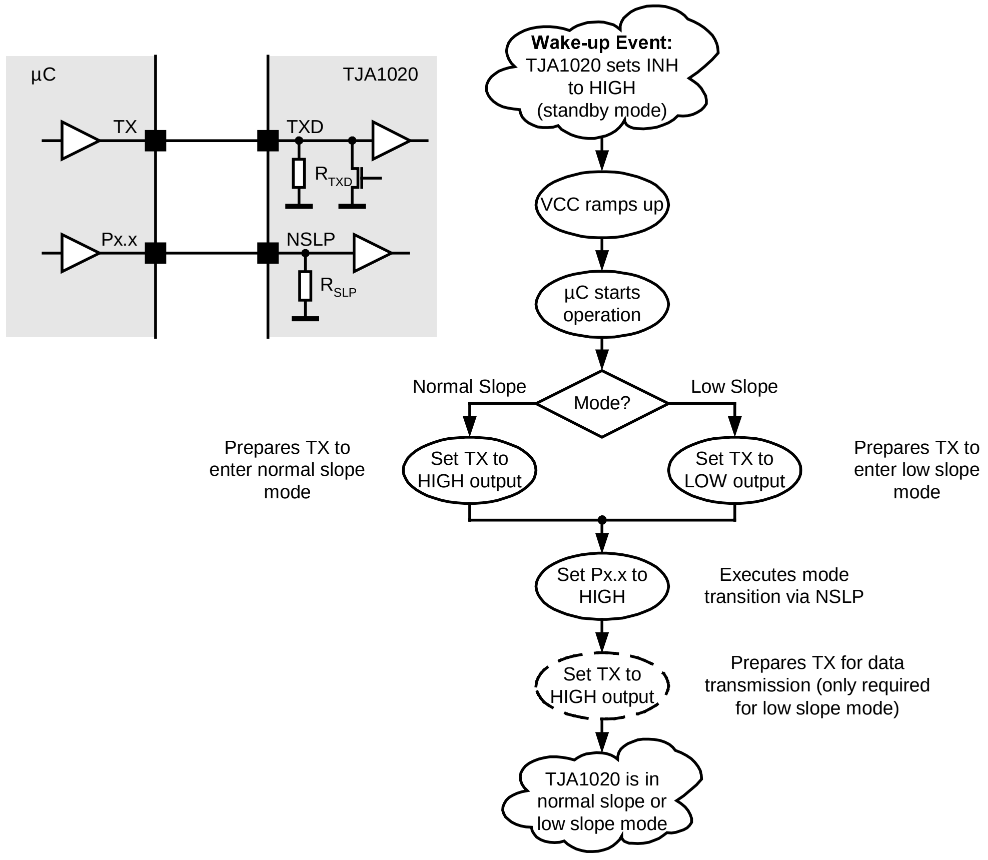


Figure 25: Flow diagram of standby to normal/low slope transition, NWAKE not used

6.2 Permanently Supplied Microcontroller

In some applications the TJA1020 is not used to control the power supply of the microcontroller. Thus the INH pin is unused, respectively used for another purpose. For such applications the TJA1020 allows a direct transition from sleep mode into normal slope mode or low slope mode.

Depending on the use of the NWAKE pin two different software-flows for mode control are recommended:

6.2.1 Application using NWAKE

Here the same flow is used as described within 6.1.1. The only difference is that no initialisation phase is performed, because the microcontroller is already running. Figure 26 shows the related software flow diagram with respect to the pin description of TXD in chapter 3.2.2.

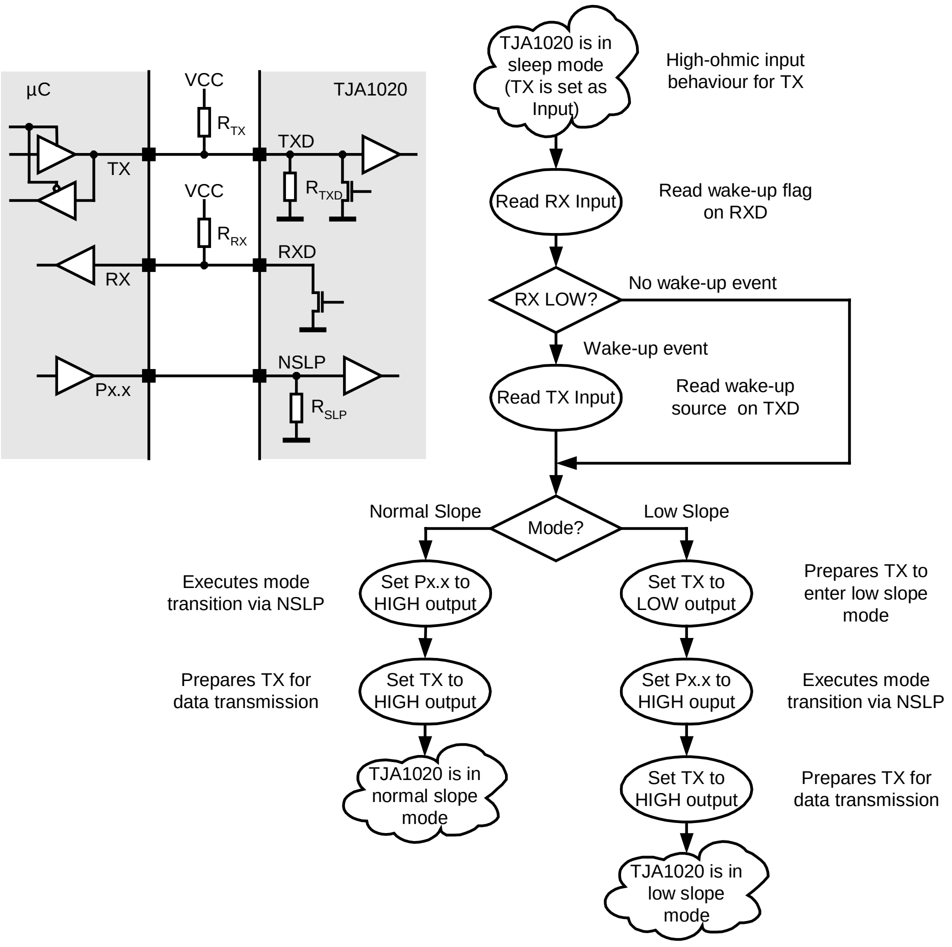


Figure 26: Flow diagram of sleep to normal/low slope transition, using NWAKE

6.2.2 Application without using NWAKE

Here the same flow is used as described within 6.1.2. The only difference is that no initialisation phase is performed, because the microcontroller is already running. The corresponding software flow diagram is shown in Figure 27.

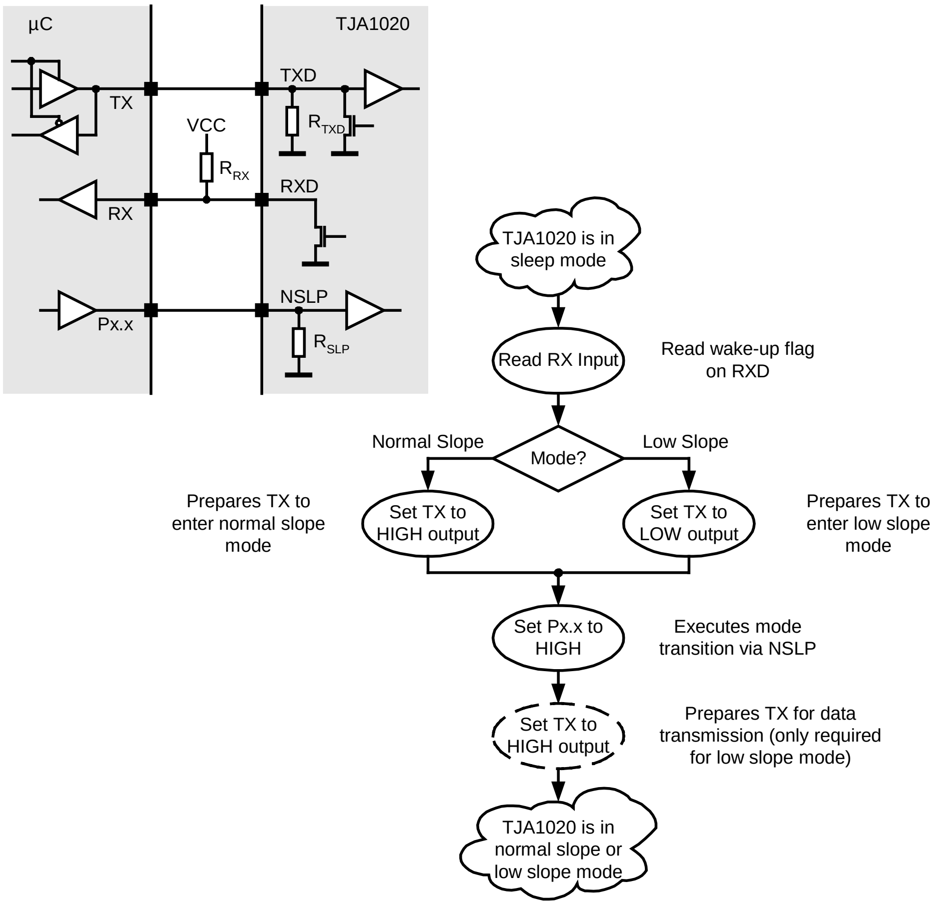


Figure 27: Flow diagram of sleep to normal/low slope transition, NWAKE not used

6.3 Transition from Normal Slope / Low Slope into Sleep Mode

The TJA1020 enters its sleep mode if the NSLP input is becoming low for at least $t_{gotosleep}$ [1].

Depending on the use of the NWAKE pin two different software-flows for mode control are recommended:

6.3.1 Application using NWAKE

If the NWAKE input of the TJA1020 is in use, the microcontroller port pin (e.g. TX) driving the TXD pin of the TJA1020 should be configured as input or bi-directional before the mode transition is executed by setting a low level on NSLP. This provides pull-up behaviour at pin TXD in case of wake-up events via NWAKE during mode transition towards sleep mode. Figure 28 shows the software flow diagram of a transition from normal slope mode or low slope mode into sleep mode with NWAKE support.

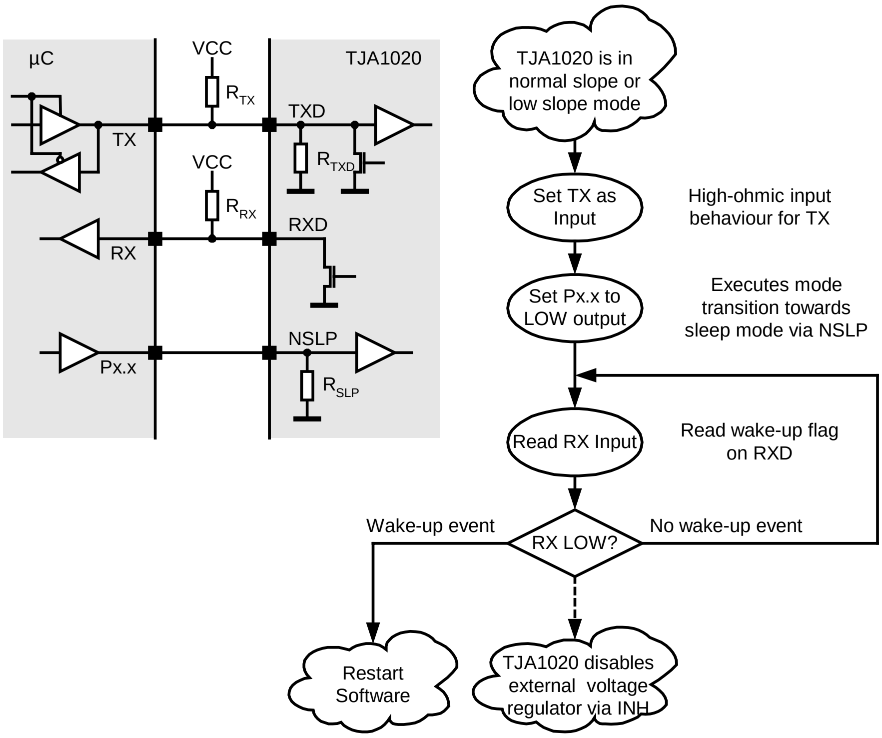


Figure 28: Flow diagram of normal/low slope to sleep transition, using NWAKE

6.3.2 Application without using NWAKE

In case the NWAKE pin is unused and no TXD pull-up behaviour is provided (see also 3.2.2.1), only the NSLP input should become low (see Figure 29). The “Set TX as Input” step within the software flow diagram in Figure 28 should not be performed, since the weak pull-down R_{TXD} [1] would cause a low level on TXD if the microcontroller port pin TX is set into a high-impedance state without pull-up behaviour. This would result in a dominant level on the LIN bus until NSLP is set low or the TXD dominant time-out phase is passed.

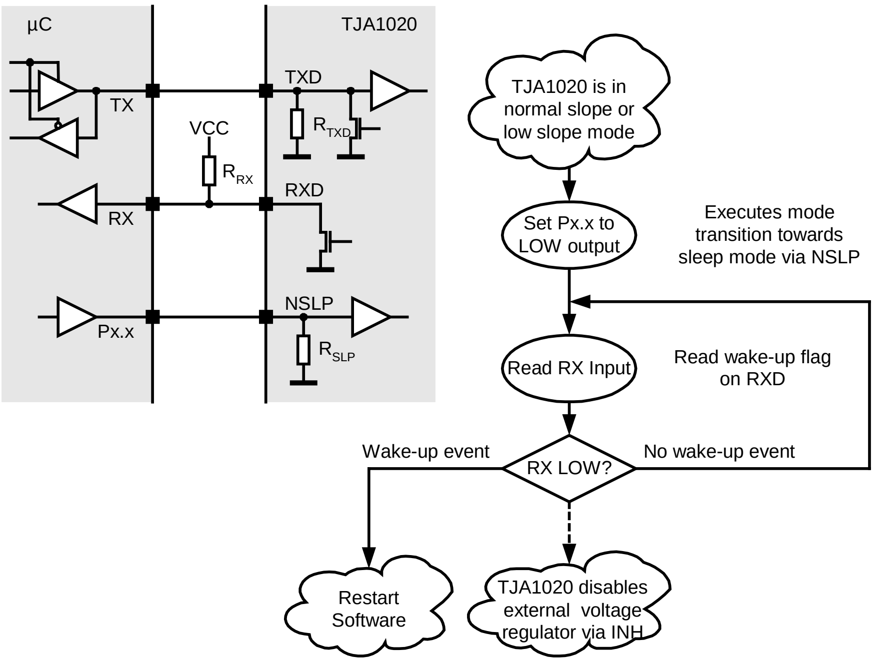


Figure 29: Flow diagram of normal/low slope to sleep transition, NWAKE not used

7. FAILURE MANAGEMENT

7.1.1 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 TJA1020 allows to reduce this short-circuit current to a minimum using its integrated termination control.

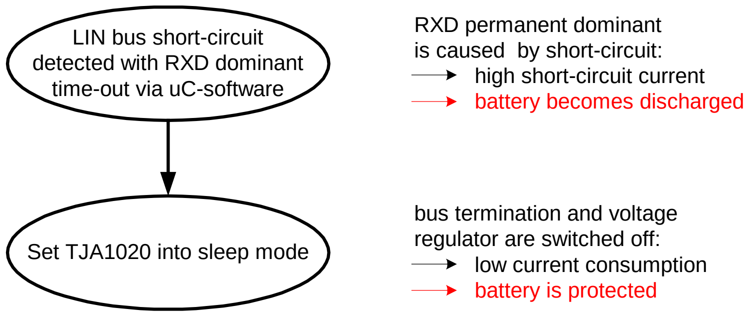


Figure 30: Failure management if LIN bus is shorted to ground

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 TJA1020 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} optimises the system with respect to fail-safe behaviour. Thus the system enters its low power mode (VCC 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 30 shows the corresponding failure management flow.

7.1.2 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 TJA1020 has an integrated TXD dominant timer. Thus the transmitter of the TJA1020 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 TJA1020.

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 7.2.

Furthermore if one of the above failures is present, a change of the NSLP 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 TJA1020 (fail-safe behaviour).

7.2 Minimum baud rate and Maximum TXD Dominant Phase

Due to the TXD dominant failure detection of the TJA1020 the maximum TXD dominant phase is limited by the minimum TXD dominant time-out time t_{DOMmin} [1]. As a consequence the transmission speed is also limited to a minimum baud rate.

7.2.1 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_{DOMmin} [1] the minimum baud rate for the master node can be calculated by the following equation:

$$baudrate_{\min,MASTER} = \frac{T_{SYNBRK,\max}}{t_{DOM,\min}}$$

with $T_{SYNBRK,max} > T_{SYNBRK,min}$

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

Thus the TJA1020 allows operating within master application down to 2.4kBaud.

7.2.2 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:

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

with n_{safe} as safety margin

Thus the TJA1020 allows operating within slave application down to 1.8kBaud.

8. POWER CONSUMPTION

During design of the TJA1020 special care has been taken on system power consumption since this is a key for introduction of this new LIN sub bus system within automotive applications. The TJA1020 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 TJA1020 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 TJA1020 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 31).

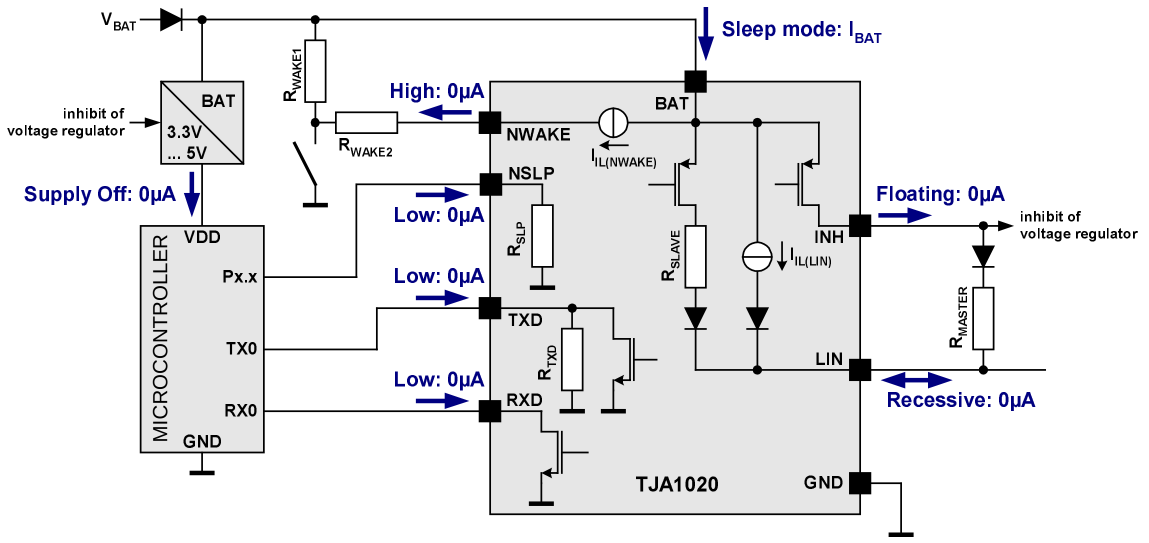


Figure 31: Current consumption in sleep mode

8.2 Sleep Mode Power Consumption at presence of LIN Bus Short-circuit

In case of a LIN short-circuit to ground the power consumption of the TJA1020 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 32).

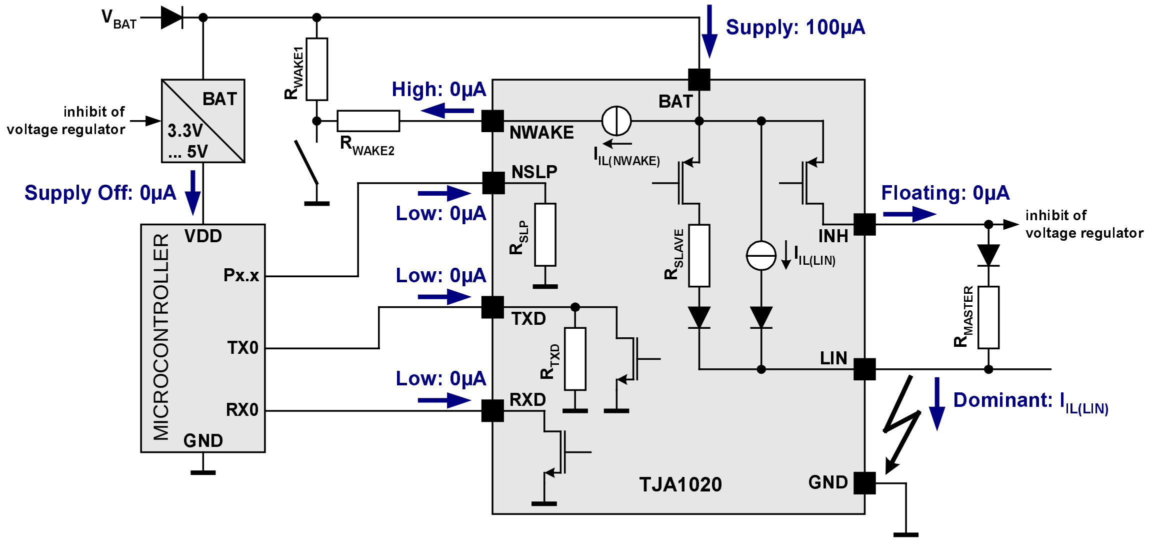


Figure 32: Typical short-circuit current consumption in sleep mode

8.3 Comparison TJA1020 Application vs. Common LIN Transceiver

Beside the very low power consumption in sleep mode the fail-safe termination concept of the TJA1020 (INH pin for master termination) allows reducing the overall system power consumption to a minimum even with short-circuits on the LIN bus line. An overview of typical system supply currents in low power mode is shown in Table 2.

	TJA1020 (master termination via INH pin)			Common LIN Transceiver (master termination connected to V_{BAT})		
	Master Node	Slave Node	6-node Network	Master Node	Slave Node	6-node Network
Sleep Mode System Current (no bus failure present)	3µA	3µA	18µA	30µA	30µA	180µA
Sleep Mode System Current (LIN shorted to ground)	100µA	100µA	600µA	12000µA	430µA	14150µA

Table 2: Overview of typical system supply currents

9. REFERENCES

[1] Data Sheet TJA1020, LIN Transceiver, Philips Semiconductors, Dec. 2001

[2] LIN Specification Package, LIN Protocol Specification – Revision 1.2, LIN Consortium, Nov. 2000

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