

Application Hints TJA1055T

Fault-tolerant CAN transceiver

Rev. 1.4 — 8 July 2011

Application Hints

Document information

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Summary

The TJA1055T is an advanced fault-tolerant CAN transceiver primarily intended for low-speed applications up to 125kBd in passenger cars. Besides the differential receive and transmit capability the transceiver provides single-wire transmitter and/or receiver in error conditions. The TJA1055T is the enhanced successor of the fault-tolerant CAN transceivers TJA1054T and TJA1054TA with the same functionality but offering in addition a number of improvements.

These application hints provide information on how to use the TJA1055T in CAN applications

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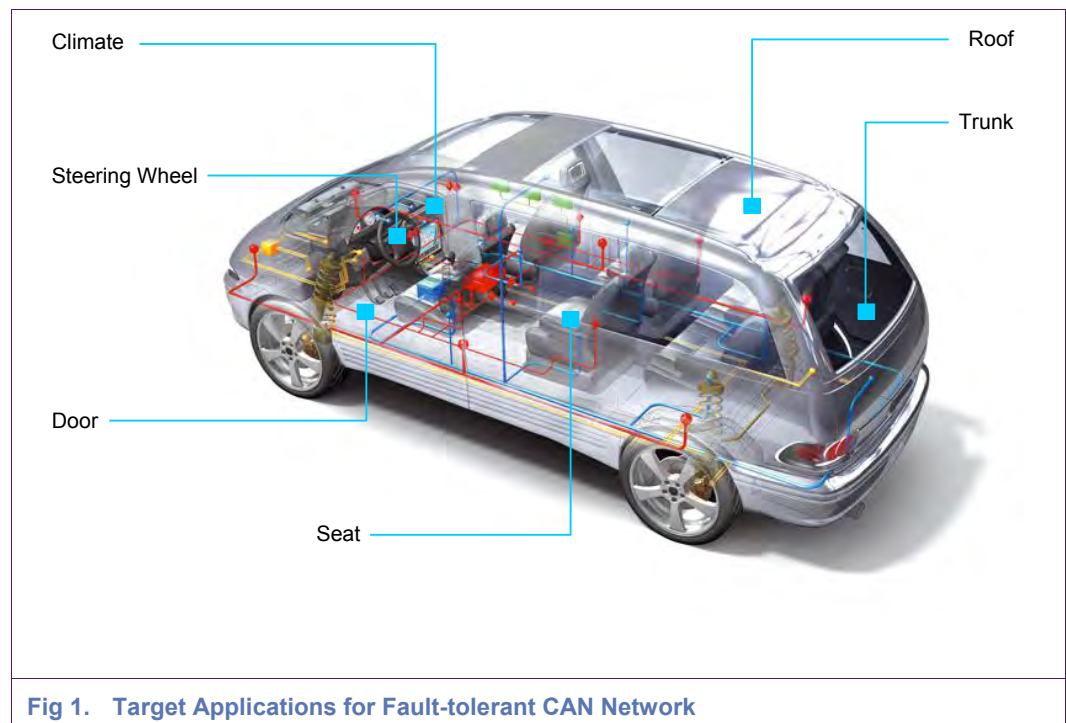
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1. Introduction

The fault-tolerant CAN transceiver TJA1055T from NXP Semiconductors provides the physical link between the protocol controller and the physical bus wires in a Controller Area Network (CAN). Additionally the transceiver is able to control one or more external voltage regulators within an Electronic Control Unit (ECU) and supports an advanced low power management to reduce the current consumption significantly. This allows the TJA1055T to enter Sleep Mode and as a result to switch off the external voltage regulators in order to deactivate the VCC supply of the transceiver and the host microcontroller. The TJA1055T has been developed mainly for low-speed CAN applications (up to 125 kBd) in passenger cars; especially for comfort electronics (see Fig 1). The device operates in differential mode but will switch to a single-wire transmitter and/or receiver in error conditions. The bus is continuously monitored to switch back to normal operating mode when faults disappear. In the supported failure cases all nodes continue to communicate.

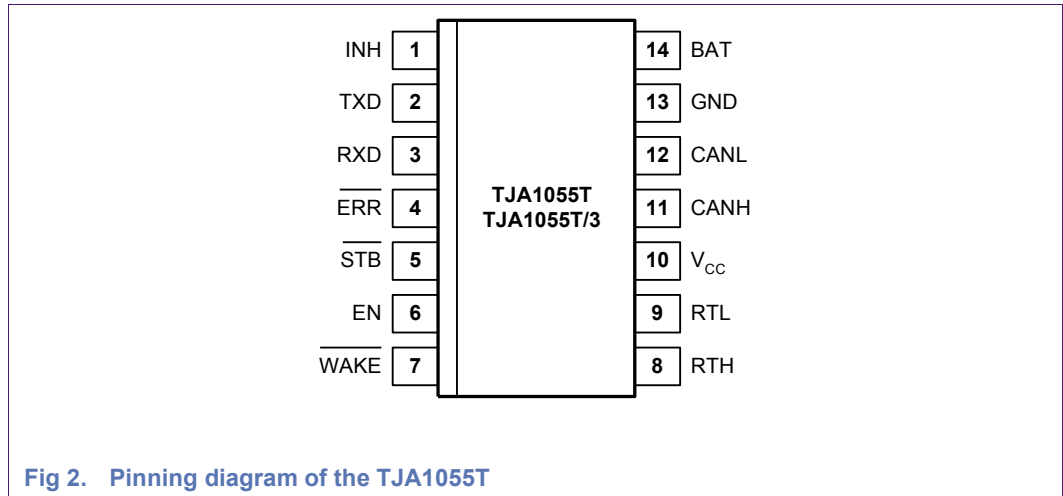


The TJA1055T is offered in two versions with different voltage interfaces towards the microcontroller. The TJA1055T is dedicated for microcontrollers with a 5V interface and the TJA1055T/3 is dedicated for microcontrollers with a 3V or 3.3V interface.

Compared to the TJA1054T(A) the TJA1055T is improved with respect to current consumption and EMC capability. Furthermore the TJA1055T is suitable to replace the TJA1054T(A) one-to-one in existing applications, if desired. The TJA1055T is the successor of the so-called "golden device" TJA1054T and thus, fully compatible with the ISO 11898-3 standard [1].

2. Overview and General Description

2.1 Pinning



Pin INH

The intention of the output pin inhibit (INH) is to control one or more voltage regulators within the ECU. Details can be found in chapter 4.2.1.

In Sleep Mode the INH pin gets floating. Due to the typical pull-down behaviour of inhibit input pins of common voltage regulators, this results in disabling the according voltage regulator and thus in disabling the VCC supply voltage of the microcontroller and the transceiver.

On any wake-up request to the TJA1055T or after a battery power-on the INH pin is pulled to the battery voltage, thus enabling the external voltage regulator. In case the INH pin is not of use, it can be left open.

Pin TXD

The TXD pin is the transmit data input pin. The transceiver receives the digital bit stream from the CAN controller to be transmitted to the CAN bus lines via pin TXD. A logical LOW level represents the dominant bus stage while a HIGH level represents the recessive bus state.

Pin RXD

The RXD pin is the receive data output for reading out the data from the bus lines. The analog bit stream received from the bus is transferred via RXD to the CAN-controller for further processing. When using a 5V microcontroller interface and a 5V transceiver this pin could be connected to the microcontroller directly. When using a 3V interface and the 3V version of the TJA1055T (TJA1055T/3) the RXD pin has additionally to be connected to VCC of the microcontroller via pull-up resistor.

Pin ERR_N

The ERR_N (Error Not) pin is used to indicate an error, a wake-up or a power-on flag. When using a 5V microcontroller interface and a 5V transceiver this pin could be connected to the microcontroller directly. When using a 3V interface and the 3V version of the TJA1055T (TJA1055T/3) the ERR_N pin has additionally to be connected to VCC of the microcontroller via pull-up resistor.

Depending on the operating mode, different flags are reflected at pin ERR_N. These flags are signals with an active LOW behaviour. In standby mode (EN = 0, STB_N = 0) the pin reflects the wake-up flag. In power-on standby mode (EN = 0, STB_N = 1) the power-on flag is signalled and in normal mode (EN = 1, STB_N = 1) the pin ERR_N indicates a bus failure condition.

Pin STB_N

STB_N (STB Not) is one of the two mode control pins of the transceiver. STB_N is the standby digital control signal. This active-low input pin is used together with the signal on pin EN to define the operation mode of the transceiver. This pin should directly connect to an output port pin of a microcontroller and provides an internal pull-down current source.

Pins EN

EN is the enable digital control signal. This input pin is used together with the signal on pin STB_N to define the operation mode of the transceiver. This pin should directly connect to an output port pin of a microcontroller and provides an internal pull-down current source.

Pin WAKE_N

The local wake-up pin (WAKE_N) is an input pin with internal pull-up to battery voltage. This pin is used for local wake-up. If WAKE_N detects a rising or falling edge, a wake-up condition is detected after a defined filter time (t_{WAKE}). The wake-up event has higher priority than the go-to-sleep command.

RTH and RTL pin description

The pins RTH and RTL are the termination resistor connections of CANH and CANL. In case of a CANH bus wire error the CANH line is terminated via RTH with higher impedance compared to failure-free operation. In case of a CANL bus wire error the CANL line is terminated via RTL with higher impedance compared to the failure-free operation. The value of the external termination resistors should be between 500Ohm and 6kOhm. The overall resistor in the whole CAN network should be about 100Ohm per line. For further information and calculation of this resistor see chapter 9.1.

CANH and CANL pin description

The transceiver is connected to the bus via pins CANH and CANL. CANL is the LOW-level CAN bus line. In normal operating mode, the value of dominant state is about 1,4V and the value of recessive state is 5V. In low-power modes, the voltage of CANL is equal to battery voltage (see also Fig 7).

CANH is the HIGH-level CAN bus line. In normal operating mode, the value of dominant state is about 3,6V and the value of recessive state as well as in low-power modes is about 0V. These pins have a high robustness with a maximum voltage of $\pm 58V$ and an ESD protection of $\pm 8kV$ human body model.

Pin VCC

The VCC supply provides the current needed for the transmitter and receiver of the TJA1055T during normal operation. The VCC supply must be designed with respect to the worst-case current consumption requirements (see chapter 4.2.7).

Pin GND

The pin GND is the ground pin and the reference value of all voltage in the transceiver. It is important to guarantee a well-defined GND connection between all ground pins within the ECU. This is important to guarantee optimum EMC behaviour of the overall system. Besides the GND connection to the outside world (cable tree) it is important to provide a good GND connection between the transceiver and the microcontroller. This is needed to keep the communication interface between microcontroller and transceiver unaffected by strong EMC injections into the bus cables.

Pin BAT

BAT is the battery supply pin of the transceiver. The battery supply ensures the local and remote wake-up capability of the TJA1055T when the VCC supply is switched off during Sleep Mode. The current consumption at pin BAT is very low and mainly supplying the digital circuitry as well as the wake-up components.

2.2 Fail Safe

The TJA1055T provides several fail-safe features to protect the local hardware and the external bus system from being disturbed. This guarantees that the vehicles CAN communication keeps ongoing in case of local ECU faults. The main safety features are shown in Fig 3.

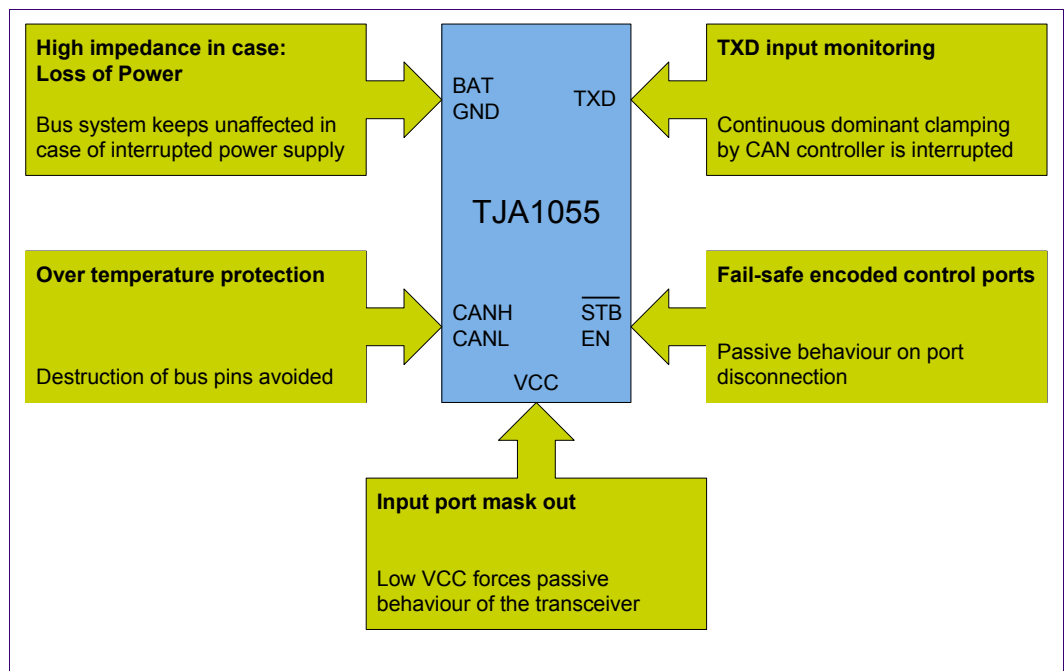


Fig 3. Overview of TJA1055T Fail-Safe features

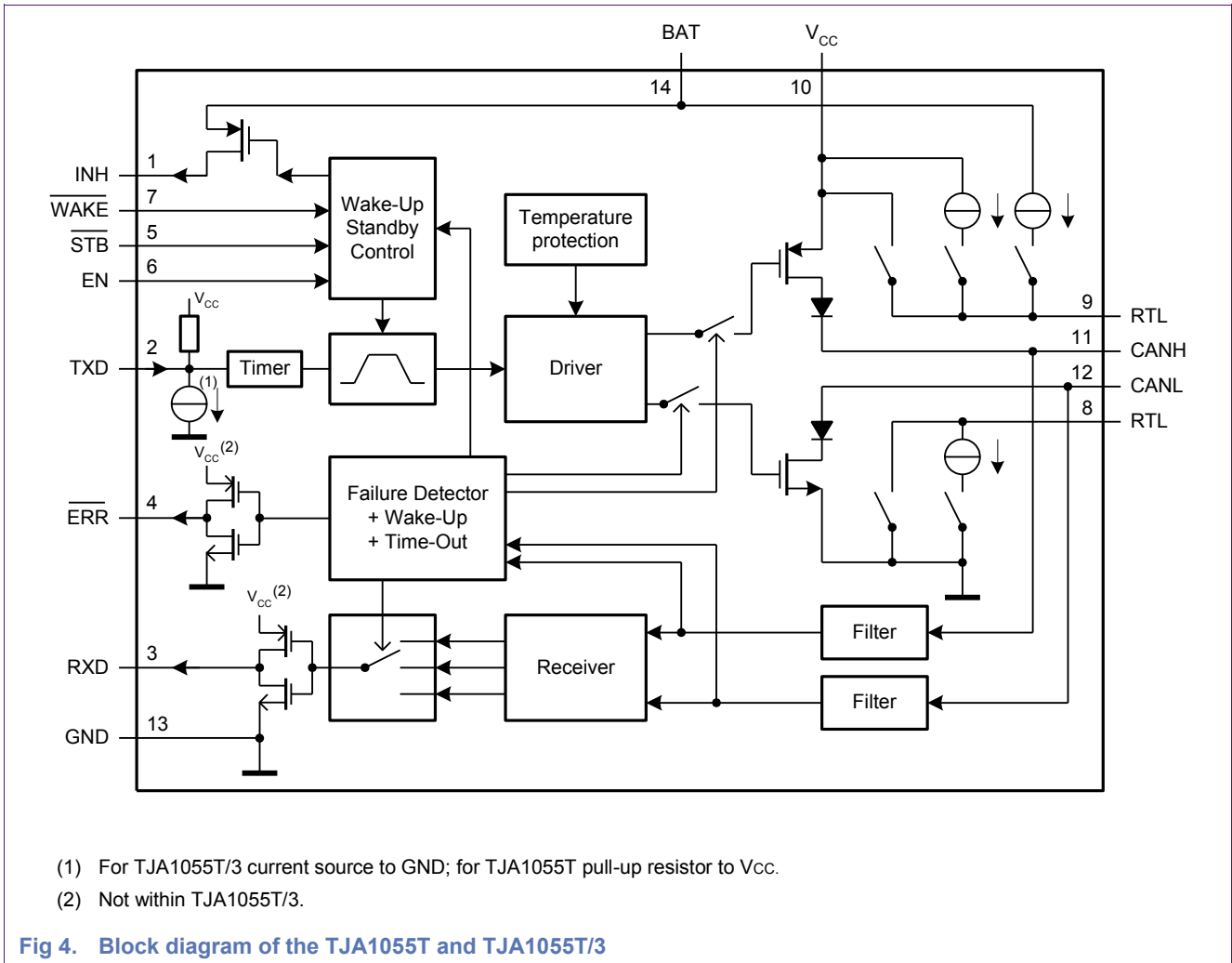
The transceiver becomes passive and keeps the bus unaffected if the transceiver loses the power connection. This is achieved by switching the pins CANH, CANL, RTH and RTL to a high impedance state.

In case the connections to the mode control pins STB_N and/or EN are interrupted an internal pull-down source sets these input pins to LOW. This makes sure that the transceiver enters a low-power mode. Besides this, the mode control of the transceiver is coded digitally in a such way that glitches on pins STB_N and/or EN during any mode change do not lead to an unwanted operation mode change. Upon loss of the VCC supply the TJA1055T enters standby mode.

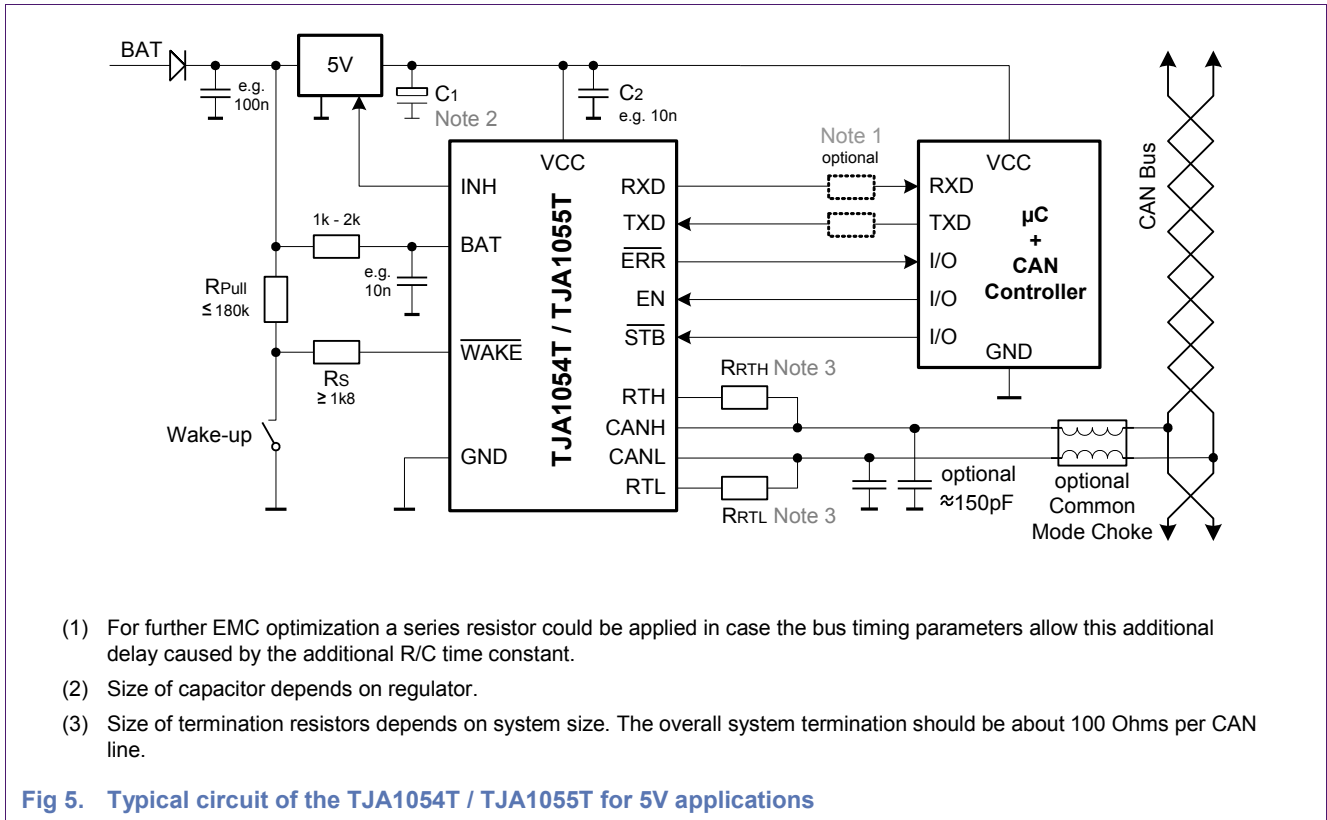
To avoid a continuous dominant clamped bus due to a clamped TXD pin a dedicated TXD dominant timeout function is provided. So, the bus cannot be permanently blocked by a single local failure.

In order to protect the transceiver from being damaged by over temperature, an according monitoring circuitry shuts down the CAN drivers until the temperature of the IC has cooled down again. Besides this, the voltage robustness on the bus pins is further increased to $\pm 58\text{V}$ for the TJA1055T compared to the TJA1054T (-27V up to $+40\text{V}$).

2.3 Block Diagram



2.4 Typical Application



2.5 Main Differences between TJA1054T and TJA1055T

The TJA1054(A)T is one to one replaceable by the TJA1055T. This chapter gives an overview to the main differences between the TJA1055T and the TJA1054AT. The limiting values and the static values are summarized in the following tables.

Please note that the data sheet values are valid in case of mismatches between data sheet values and values listed below.

Table 1 Limiting values

Symbol	Parameter	Condition	TJA1054AT		TJA1055T		Unit
			Min	Max	Min	Max	
V _{CANH}	CANH bus line voltage	With respect to any other pin	-27	+40	-58	+58	V
V _{CANL}	CANL bus line voltage	With respect to any other pin	-27	+40	-58	+58	V
V _{I(WAKE)}	Input voltage on pin WAKE_N	With respect to any other pin	-0,3	V _{BAT} +0,3	-0,3	+58	V
V _{RTH}	Voltage on pin RTH	With respect to any other pin	-0,3	V _{BAT} +1,2	-58	+58	V
V _{RTL}	Voltage on pin RTL	With respect to any other pin	-0,3	V _{BAT} +1,2	-58	+58	V
V _{ESD}	Electrostatic discharge voltage	HBM (human body model)					
		Pins RTL, RTH, CANL and CANH	-4	+4	-8	+8	kV
		All other pins	-2	+2	-2	+2	kV
		IEC 61000-4-2 (150 Ohm and 330 pF)					
		Pins RTL, RTH, CANL and CANH	-1,5	+1,5	-6	+6	kV

Table 2 Static characteristics of power supply pins VCC and BAT

Symbol	Parameter	Condition	TJA1054T			TJA1055T			Unit
			Min	Typ	Max	Min	Typ	Max	
V _{CC(STB)}	Supply voltage for forced standby mode (fail safe)		2,75	-	4,5	3,2	-	4,5	V
I _{CC}	Supply current	Normal operating mode; V _{TXD} =V _{CC} (recessive)	4	7	11	2,5	6	10	mA

Symbol	Parameter	Condition	TJA1054T			TJA1055T			Unit
			Min	Typ	Max	Min	Typ	Max	
		Normal operating mode; $V_{TXD}=0V$; (dominant); no load	10	17	27	3	13	21	mA
		Low power modes; $V_{TXD}=V_{CC}$	0	0	10	0	0	5 ¹	μA
V_{BAT}	Battery voltage on pin BAT	No time limit	-0,3	-	+40	-0,3	-	+40	V
		Operating mode	5,0	-	27	5,0	-	40	V
		Load dump	-	-	40	-	-	58	V
I_{BAT}	Battery current on pin BAT	All modes and in low power modes at: $V_{RTL}=V_{WAKE}=V_{INH}=V_{BAT}$							
		$V_{BAT} = 14V$	10	30	50	10	25	40	μA
		$V_{BAT} = 5V$ to 40V	5	30	125	10	25	100 ²	μA

Table 3 Static characteristics of input pins STB_N, EN and TXD

Symbol	Parameter	Condition	TJA1054T			TJA1055T			Unit	
			Min	Typ	Max	Min	Typ	Max		
V_{IH}	HIGH-level input voltage		0.7x V_{CC}	-	$V_{CC} + 0.3$	2.2	-	6	V	
V_{IL}	LOW-level input voltage		-0.3	-	0.3x V_{CC}	-0.3	-	0.8 ³	V	
I_{IH}	HIGH-level input current									
		Pins STB_N, EN	$V_I = 4V$	-	9	20	-	11	21	μA
		Pin TXD (54/55)	$V_I = 4V$	-200	-80	-25	-160	-80	-40	μA
I_{IH}	HIGH-level input current									
		Pins STB_N, EN	$V_I = 1V$	4	8	-	2	11	-	μA
		Pin TXD (54/55)	$V_I = 1V$	-800	-320	-100	-400	-240	-100	μA

1. This parameter is specified up to $T_{amb} = -40^{\circ}C$ to $+85^{\circ}C$
 2. This parameter is specified up to $T_{amb} = -40^{\circ}C$ to $+125^{\circ}C$
 3. This parameter adapted to support 3V interfaces

3. Fault-tolerant Physical Layer

3.1 The FT-CAN Principe

The raising count of ECU in vehicles, especially in comfort electronics, resulted in new and advanced requirements for car bus physical layer. The CAN bus protocol provides a high robustness against communication errors, but the physical layer was the weak point (wires, connectors, etc) in a standard CAN network.

For that reason the fault-tolerant CAN (FT-CAN) was specified. It uses the redundancy two-wire communication to switch into a single wire communication in case of bus fault. This requires an enhanced termination concept. Each transceiver in a FT-CAN network must have a termination resistor for CANL and CANH. That allows developing distributed non-linear network topologies with multiple stars. For further information about the termination concept see chapter 9.1.

Additional a FT-CAN transceiver has integrated an autonomous bus failure management (BFM) in order to provide reliable failure detection with well-defined and consistent fallback behaviour. The BFM provides fault tolerance regarding all single failures like shorts to ground or power supply or wire interruption. Switching into single wire communication in case of an error takes no longer than some milliseconds. For information about the BFM and the transceiver behaviour see chapter 9.2.

The FT-CAN transceivers TJA1054T and TJA1055T provide following features:

- Differential two-wire communication
- Autonomous single wire communication in case of bus fault
- Flexible topologies

3.2 Network Architectures

An example of a typical fault-tolerant CAN network is illustrated in Fig 6. Each ECU is connected to the network via a stub line. The networks architecture itself may be in star and/or linear topology. Fig 6 describes the basic structure of an ECU. Usually it consists of a microcontroller with integrated CAN controller and a transceiver for the physical connection to the bus. A voltage regulator supplies both, the microcontroller and the transceiver, with the V_{CC} voltage. Via the transceivers INH pin the voltage regulator is controlled. Switching off the INH pin deactivates the V_{CC} supply of the transceiver and the microcontroller. This reduces the current consumption of the ECU and helps to prevent the battery being discharged. For more information about the INH pin and its functionality please refer to chapter 4.2.1.

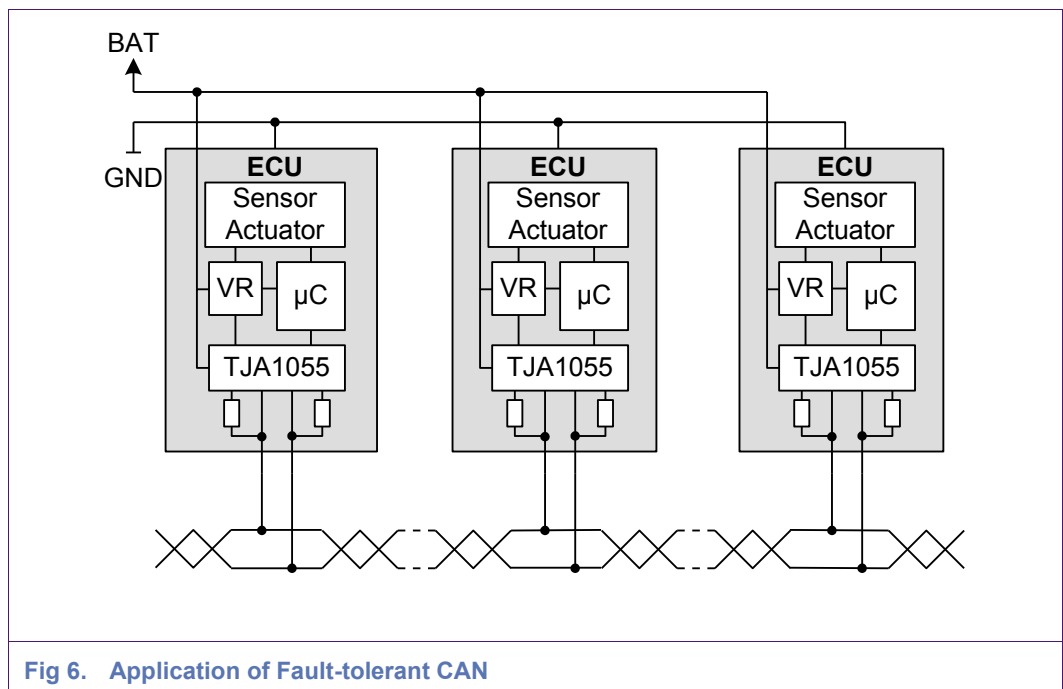


Fig 6. Application of Fault-tolerant CAN

3.3 Bus Level Scheme

During normal CAN communication the CAN controller transmits a serial data stream to the TXD input pin of the transceiver. An internal logic converts this data stream to the differential bus signals on CANH and CANL. In fault-tolerant CAN networks different bus voltage levels are provided depending on the actual operation mode.

When the transceiver is in Normal Mode and additionally the bus is idle, the CANL line is terminated to VCC and the CANH line is terminated to GND. RXD and TXD are on HIGH level. This is the so-called recessive state. When logic LOW-level is applied to TXD the output drivers of CANH and CANL change their states, thus generating the so-called dominant state on CAN bus lines. CANL will be driven towards GND level and CANH towards VCC level. The RXD pin becomes LOW by receiving the dominant bus level.

Besides the Normal Mode the transceiver provides three Low-power Modes. In these modes the CANL line is terminated to BAT while the CANH line is terminated to GND. An overview of bus voltage levels is shown in Fig 7. To distinguish between dominant and recessive states the differential voltage V_{diff} is determined:

$$V_{diff} = V_{CANH} - V_{CANL}$$

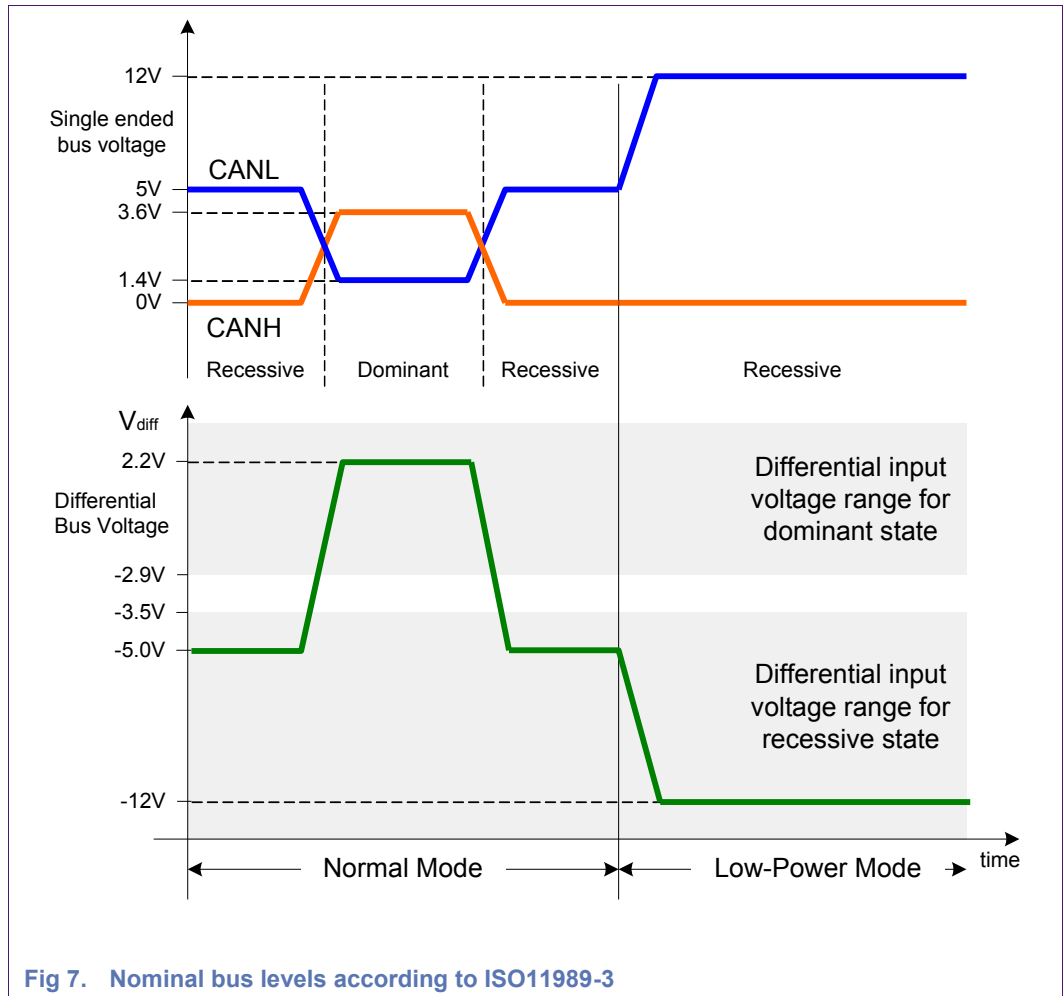


Fig 7. Nominal bus levels according to ISO11989-3

The receiver converts the differential bus signal to a logic level, which is signaled at the RXD output. The serial receive data stream is provided to the CAN protocol controller for decoding. The receivers input comparator is always active and consequently monitors the bus also while the bus node is transmitting a message itself. This is required to support the bit-by-bit arbitration scheme of CAN.

4. Hardware Design

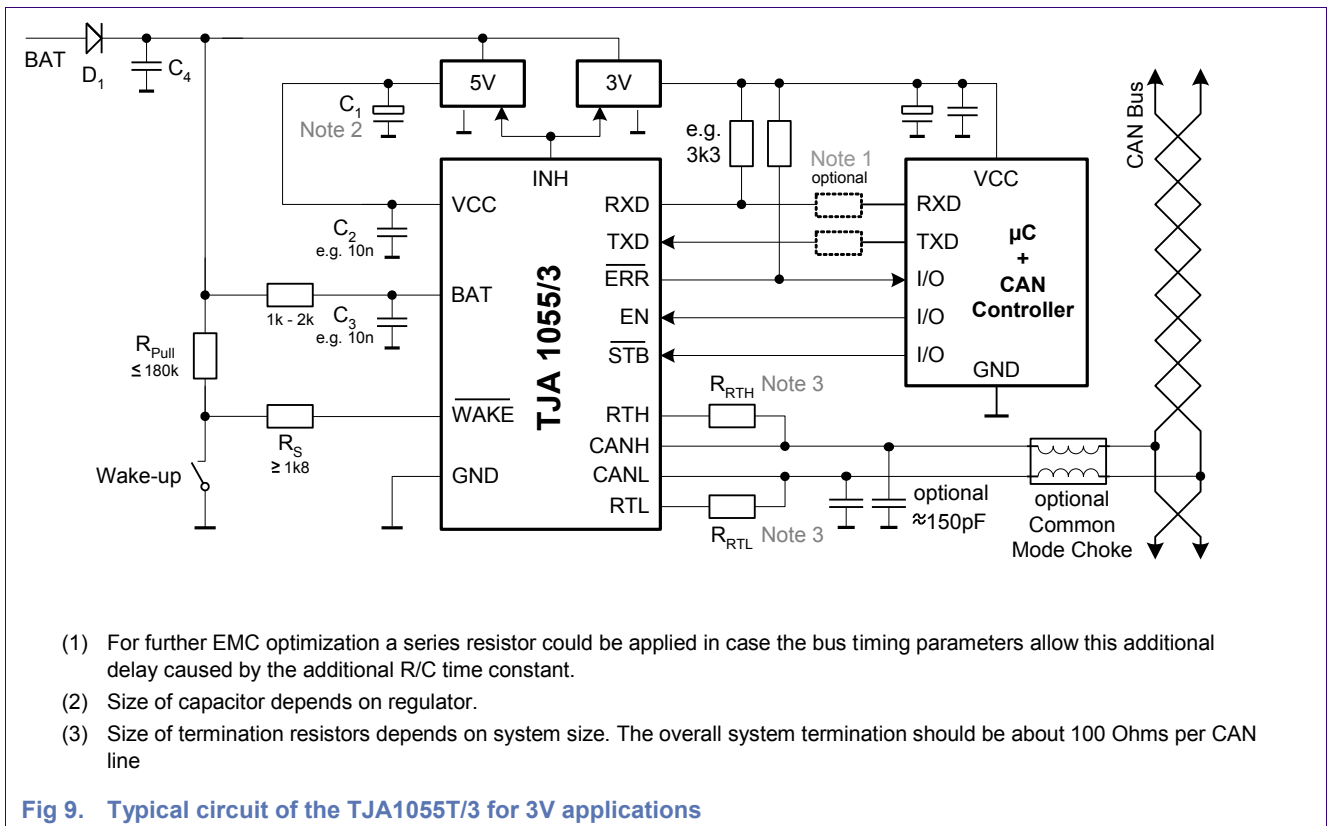
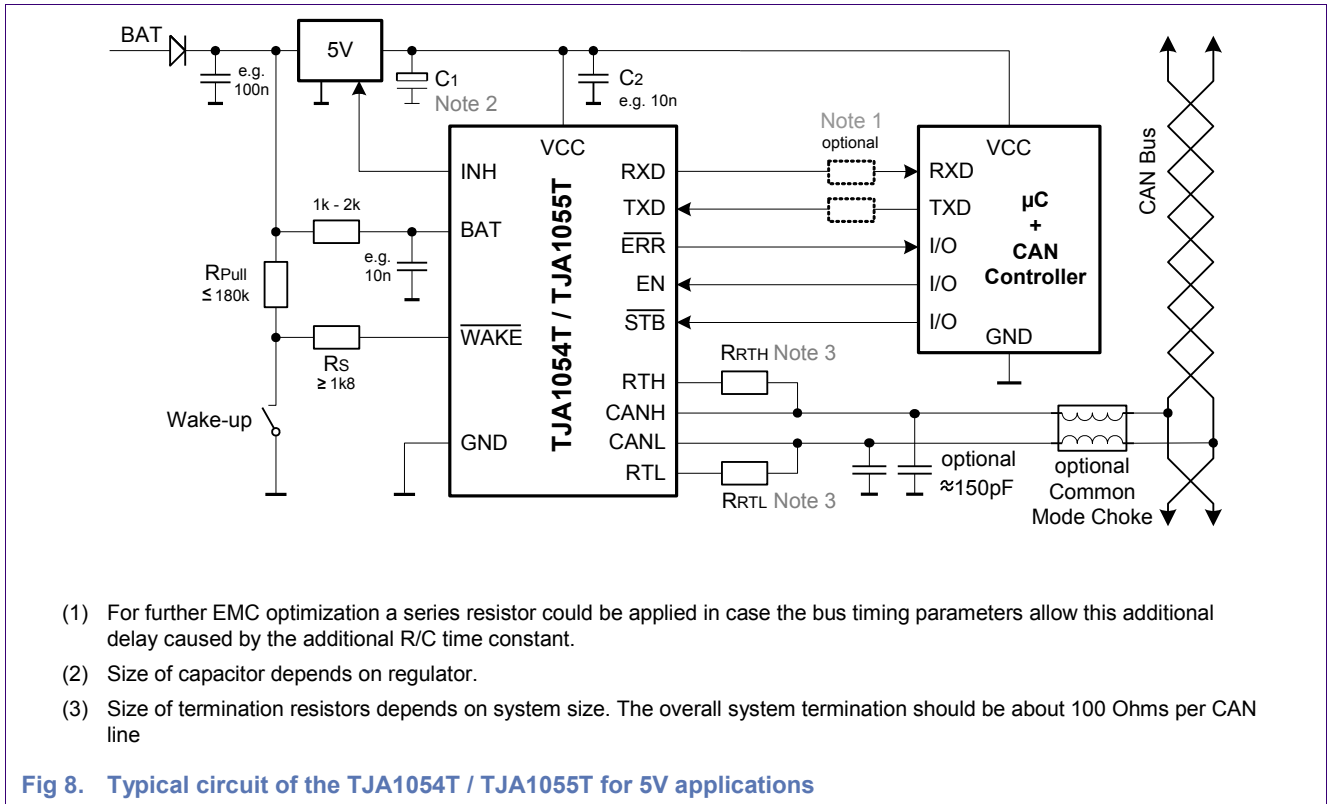
4.1 Application Diagram 3V and 5V

Fig 8 shows a typical circuit diagram for the fault-tolerant CAN transceivers TJA1054(A)T and TJA1055T. For the 3V version of the TJA1055T a typical circuit is given in Fig 9 to support microcontrollers with a 3V or 3.3V interface.

The only differences between the 5V and the 3V version of the TJA1055T are the additional required pull-up resistors on RXD and ERR_N for the TJA1055T/3 to get independent from the 5V supply of the transceiver. The INH circuit, the power supply circuit, the wake pin circuit and the CAN bus circuit are equal for the 5V and the 3V version. Layout differences can only be found in the microcontroller and transceiver interface. As shown in the block diagram of the TJA1055T the pins RXD and ERR_N of the 3V version do not provide a high side driver. Thus, the transceiver is not able to pull these pins to 3V. In Fig 9 the external required pull-up resistors for RXD and ERR_N are depicted. The size of these resistors should be e.g. 3,3kOhm to get an acceptable throughput time.

The circuit diagram is split into five main sections in order to give an example layout for the TJA1054(A)T and TJA1055T. These examples are:

- INH Circuit Example
- Wake Pin Circuit
- CAN bus circuit
- μ C- Transceiver Interface
- BAT and VCC Supply Circuit

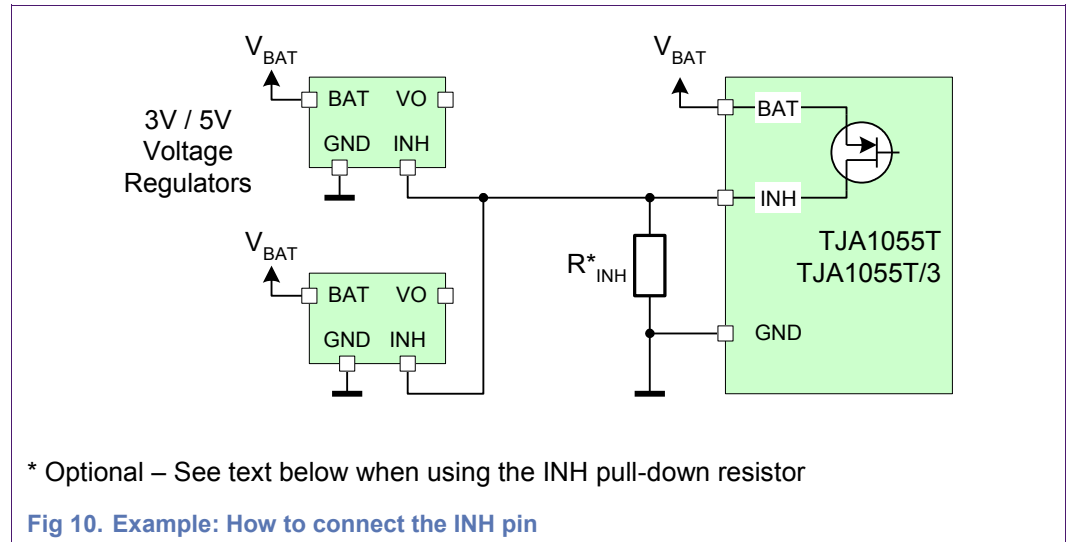


4.2 Application Details

4.2.1 INH Circuit Example

The INH pin is used to control one or more external voltage regulator(s). The transceiver INH output pin is usually directly connected to the INH input pin of the voltage regulator(s). An example schematic is illustrated in Fig 10.

Please note, that a pull-down load is required due to the possible leakage current to battery.



Maximum pull-down resistor R_{INH}

In Sleep Mode INH is floating and in all other Modes the pin provides V_{BAT} level. The most voltage regulators have an pull-down behaviour at their INH input pins, so a floating INH pin on the transceiver switches off the voltage regulator. If there is no pull-down integrated an external pull-down resistor has to be connected. To dimension the maximum value of the pull-down resistor the leakage current of INH pin (see TJA1055T datasheet [2]) and the shut down threshold of a voltage regulator have to be taken into account.

Table 4 Example values for resistor calculation

Symbol	Parameter	Value	Unit
$ I_L $	Leakage current of INH pin	5	μA
V	Shut down threshold of a voltage regulator	1,5	V

The maximum size of the external resistor calculates to

$$R_{INHMAX} = 1,5V / 5\mu A = 300k\Omega.$$

Maximum ON resistance of INH

The INH driver of the TJA1055T is designed with a self-protected high-side switch towards BAT. The maximum ON resistance calculates to

$$0.8V / 180\mu A = 4k4 \text{ (MAX)} \text{ (see also datasheet, } \Delta V_H, \text{ HIGH-level voltage drop)}$$

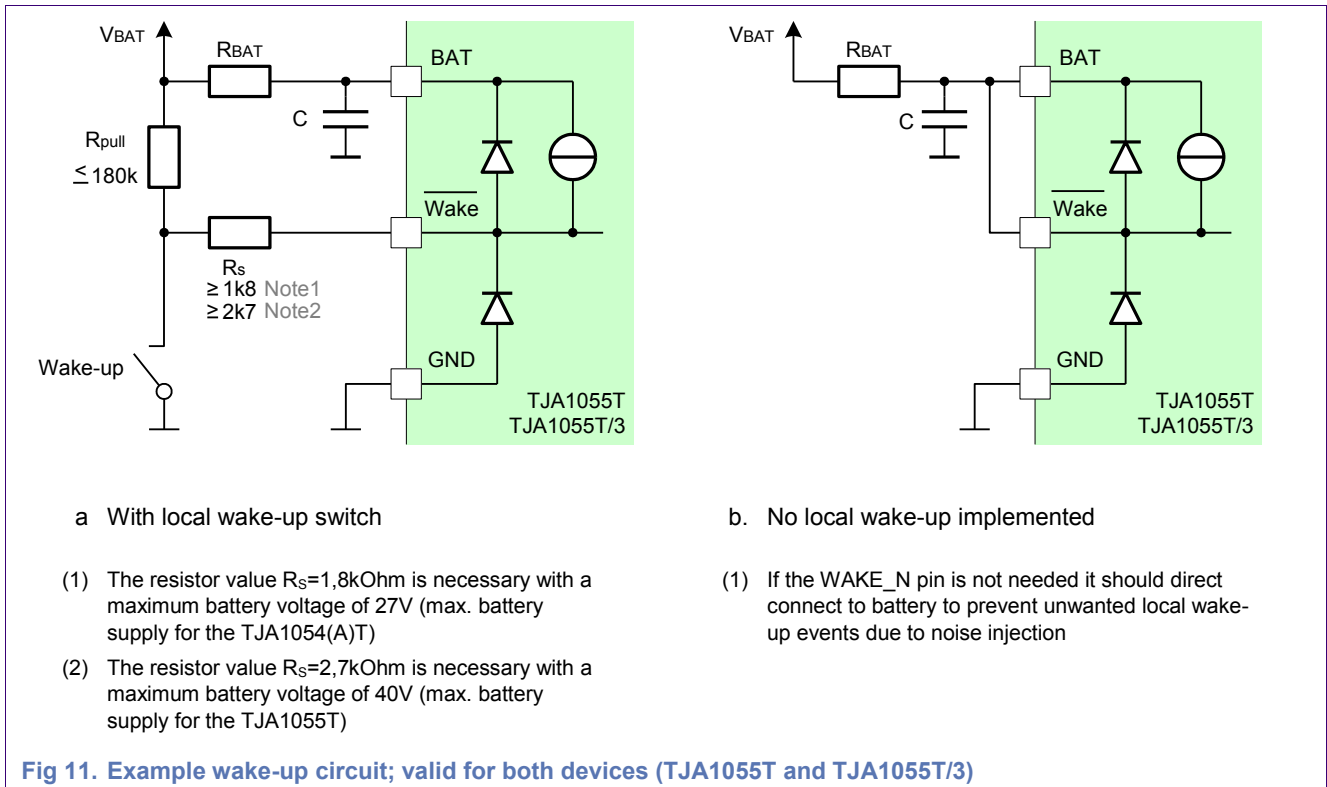
So, within a certain range of output current, this worst-case pull-up resistance of 4,4kOhm is present at the INH output stage, in case it is switched on. Since the MOS transistor has a certain channel size, it can deliver a limited amount of output current within the linear operating area. Starting at about 4mA output current the linear range is left and the resistance will increase. Thus, the output will limit the short circuit current implicitly.

For applications it is recommended not to drive more than about 1mA out of the INH pin. Nevertheless the device will not be destroyed, even if the INH is shorted to GND. Due to lifetime issues it is recommended not to exceed 1mA permanently.

4.2.2 Wake_N Pin Circuit

The WAKE_N pin is used for local wake-up and is both edges sensitive. It has an internal weak pull-up current source toward VBAT in order to prevent an unwanted local wake-up during an open wire at pin WAKE_N. If the WAKE_N pin is not needed it should directly connect to the BAT pin without any additional components (Fig 11b). This prevents leakage current from battery to ground.

If the local wake-up feature shall be implemented a wake-up circuit as shown in Fig 11a should be used. The WAKE_N pin is connected to VBAT via pull-up resistor. A series resistor R_S is added in order to limit the current in case of lost of ground. For detailed description see below:



Remark:

Current limitation resistor R_S for WAKE_N pin

As shown within the application diagram (Fig 8) of the fault-tolerant transceivers and in the figure above, a series resistor R_S in front of the pin WAKE_N is recommended in case an external switch to GND should be applied. Purpose of this resistor is to limit the current, if the control unit has lost its GND connection. This resistor is needed only in case the ECU might lose its GND connection (due to a contact failure) while the external wake-up source connected to the pin WAKE_N still is connected to GND.

In case of a GND loss on ECU level there is the possibility that the entire control unit becomes connected to GND via the external wake-up switch to an independent GND source (see also Fig 12). In order to limit the current in this special failure case a series resistor is required to protect the transceiver.

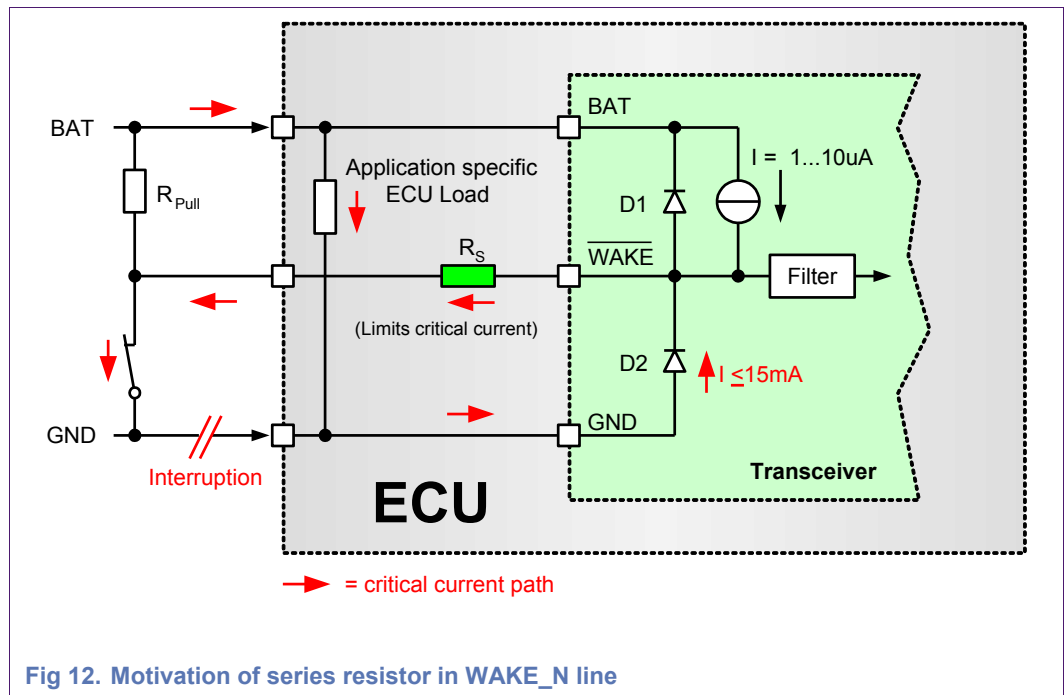


Fig 12. Motivation of series resistor in WAKE_N line

The pull-up resistor R_{PULL} shown within Fig 12 is used to guarantee a defined current within the external wake-up switch to GND in case it is closed. This current is needed to provide a good contact within the mechanical switch itself (wetting current etc.). The transceiver's integrated pull-up current source to BAT is not suitable to provide sufficient current for the application and is used only to get a defined level at the pin WAKE in case of an open circuit condition.

Following the range of R_S is shown. The value of the series resistor R_S connected to the pin WAKE_N is limited by parameters summarised in Table 5. The maximum allowed current for the pin WAKE_N could be found within the "LIMITING VALUES" of the corresponding transceivers data sheet. The input threshold voltage and pull-up current for the pin WAKE_N can be found within the "DC Characteristics" section of the corresponding transceivers data sheet. The relevant values are also collected within the following table.

Table 5 Parameters defining the range of R_s

Symbol	Description	TJA1054(A)T	TJA1055T
I_{WAKE}	The maximum allowed current for the pin WAKE_N	-15mA	-15mA
$V_{th(wake)}$	The input wake-up threshold voltage of the pin WAKE_N	2,5V	2,5V
I_{IL}	The maximum internal pull-up current of the pin WAKE_N	10uA	10uA
V_{GNDMAX}	The maximum system GND offset between ECU and the external wake-up switch, which should be tolerated (e.g.)	0,5V	0,5V
V_{BATMAX}	The maximum battery supply voltage	27V	40V

Calculating the limits of R_s

The maximum possible series resistor R_s is defined by the wake-up threshold of the pin WAKE, the GND shift between the ECU and the transceiver and the integrated pull-up current source of the pin WAKE. Following formula allows calculation of the maximum allowed series resistor:

$$V_{RSMAX} = V_{th(WAKE)MIN} - V_{GNDMAX}$$

$$R_{SMAX} = \frac{V_{RSMAX}}{I_{IL}} = \frac{(V_{th(WAKE)MIN} - V_{GNDMAX})}{I_{IL}}$$

with V_{GND} = GND shift between Transceiver and wake – up switch

The minimum allowable series resistor R_s is defined by the maximum allowable input current for the pin WAKE. This maximum current must not be exceeded, even if VBAT reaches its maximum voltage level. Thus the minimum series resistor R_s calculates as follows

$$R_{SMIN} = \frac{V_{BatMAX}}{I_{WAKE}}$$

Example calculation

Assuming proper wake-up with 0,5V GND shift between the wake-up switch and the transceiver chip the maximum possible series resistor is calculated as follows (TJA1055T).

$$R_{SMAX} = \frac{(V_{th(WAKE)MIN} - V_{GNDMAX})}{I_{IL}} = \frac{(2.5V - 0.5V)}{10\mu A} = 200k\Omega$$

$$R_{SMIN} = \frac{V_{BatMAX}}{I_{WAKE}} = \frac{40V}{15mA} = 2.7k\Omega$$

Table 6 Maximum and minimum values of R_S

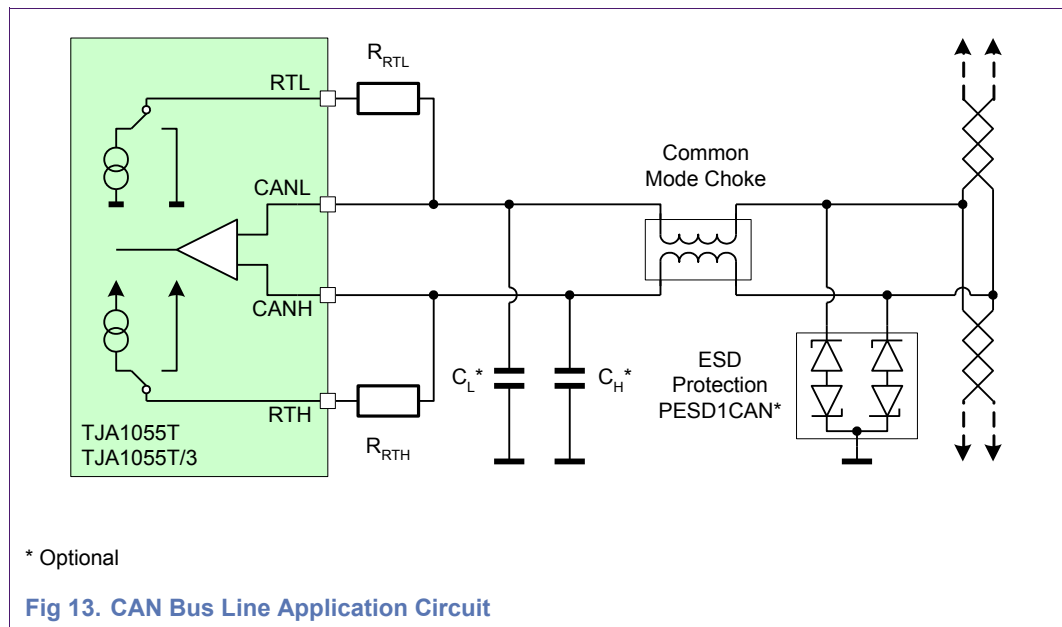
Conditions: GND shift $V_{GNDMAX}=0,5V$; battery supply $V_{BATMAX1054}=27V$ and $V_{BATMAX1055}=40V$

Symbol	Description	TJA1054(A)T	TJA1055T
R_{SMAX}	Maximum series resistor	200kOhm	200kOhm
R_{SMIN}	Minimum series resistor	1,8kOhm	2,7kOhm

Note: The minimum value $R_S=2,7kOhm$ for the series resistor is only necessary in application with a maximum battery voltage of 40V. In normal passenger car applications the battery voltage is 12V and in truck applications 24V. So, there are no changes required if the TJA1054T is replaced by the TJA1055T since there is no difference in the device specification regarding this topic.

4.2.3 CAN Bus Circuit

The communication in a CAN network takes place via CANH and CANL. The device pins CANH and CANL are directly connected to according bus lines. In low-power modes and in case of bus fault the CAN transmitter of the transceiver are disabled. Hence the bus pins are connected via termination resistor to RTH (CANH) and RTL (CANL) to achieve a defined output state with predefined impedance. A schematic is illustrated in Fig 13.



The value of the resistors R_{RTH} and R_{RTL} should be between 500Ohm and 6kOhm. The overall resistor in the whole CAN network should be about 100Ohm. For further information and calculation of this resistor see 9.1. To improve the EMC behaviour of a FT-CAN network an optional common mode choke and capacitors could be added. The TJA1055T provides already a high ESD robustness. Further increase in ESD capability is possible with adding the PESD1CAN, if required. For further details see chapter 6.

4.2.4 μ C- Transceiver Interface

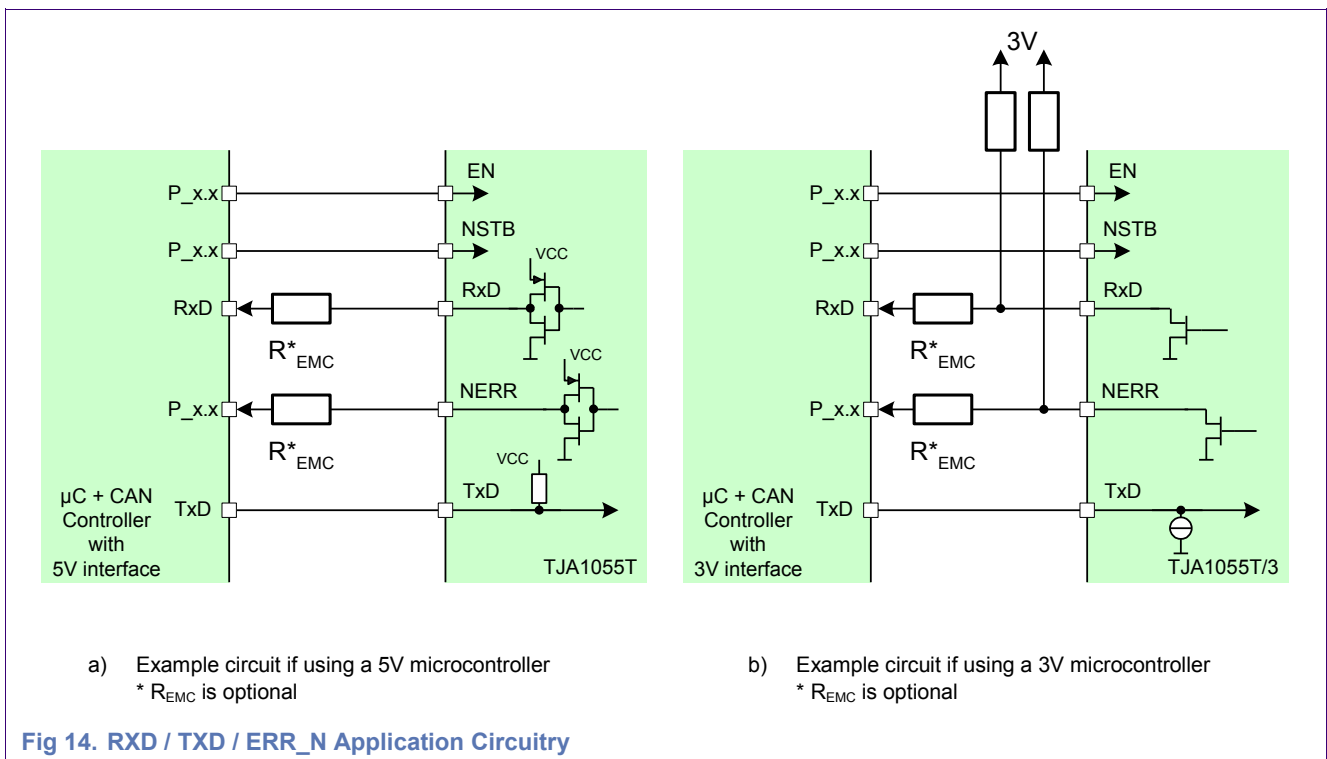
4.2.4.1 Mode Pins EN and STB_N

The mode pins EN and STB_N control the operating modes of the TJA1055T. The transceiver provides four different modes. All modes different from normal mode are low-power modes. In these modes the current consumption is reduced significantly. The pins STB_N and EN are needed to change the transceiver operating modes as described in chapter 5.1. They are connected to a microcontroller port independently of using 3V or 5V version.

4.2.4.2 Pins TXD, RXD and ERR_N

The pins RXD and TXD are the input / output pins of the CAN controller. Data that shall be transmitted is send to the transceiver via TXD. The CAN controller listens to RXD simultaneously and evaluates the received data from the transceiver. The TXD pin can be connected directly to the dedicated 3V or 5V microcontroller interface pin.

Pin ERR_N is connected to a microcontroller port to readout an error state or one of the transceiver flags. The pins RXD and ERR_N of the 5V version provide a high-side and low-side driver, so no external pull-up resistors are needed. For the 3V version of the TJA1055T the pins RXD and ERR_N need additional external pull-up resistors (see below for the calculation of the minimum pull-up resistor). That is the only difference between these two devices. The example schematic is shown in Fig 14a and for the 5V transceiver and in Fig 14b for the 3V version.



4.2.4.3 Example Calculation of Minimum Pull-up Resistor for RXD and ERR_N

In the TJA1055T/3 is no internal pull-up path to VCC therefore an external pull-up resistor is needed. In order to guarantee a voltage threshold for dominant and recessive states a minimum value for the pull-up resistor is required. The RXD and ERR_N pins

must be able to pull-down the voltage level on the microcontroller input pin below the minimum dominant threshold. In active state there is a voltage divider consisting of the pull-up resistor $R_{pull-up}$ and the internal transistor resistance R_{DSon} (see Fig 15).

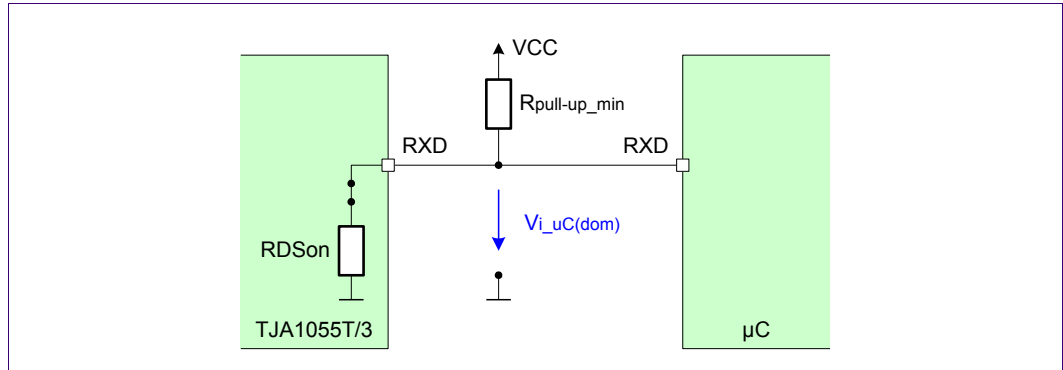


Fig 15. Simple circuitry example of RXD and ERR_N

The transistor resistance R_{DSon} can be calculated using the data sheet parameter I_{OL} (LOW-level output current) [2]. On order to calculate the maximum R_{DSon} the minimum output current must be taken into account, which is specified with 1.3mA at an output voltage of 0.4V.

$$R_{RDSon} = \frac{V_o}{I_{OL}} = \frac{0.4V}{1.3mA} = 308\Omega$$

Based on this maximum R_{DSon} resistance the pull-down current can be calculated, which is needed to achieve the minimum input threshold for dominant state for the microcontroller pins. For this example the minimum input voltage of the microcontroller for dominant state is assumed to be $0.3 \times VCC$ with $VCC = 3V$.

$$I_{pull-down} = \frac{V_{I_uC(dom)_min}}{R_{RDSon}} = \frac{0.3VCC}{R_{RDSon}} = 2.9mA$$

With this values the minimum pull-up resistor calculates to:

$$R_{pull-up_min} = (VCC - V_{I_uC(dom)_min}) / I_{pull-down} = 725\Omega$$

Conclusion: The pull-up resistor for ERR_N and RXD should be higher than 725Ω for a 3V application. The calculation above is an example only. It has to be re-calculated with the real values of the microcontroller interface specification and the tolerances of VCC as well as a possible microcontroller-internal pull-up resistance.

4.2.4.4 Usage of Series Resistors R_{EMC}

In Fig 14 two optional series resistor R_{EMC} in RXD and TXD wires between the μC and the transceiver may be included to further improve the EMC performance of the ECU. In case signals at TXD show fast slopes, this may cause a degradation of the system EMC performance. Here it is recommended to place a series resistor of about 1kΩ into the TXD line between transceiver and microcontroller. Along with pin capacitance this would help to smooth the edges to some degree. For high bus speeds (close to max. 125kbit/s) the additional delay within TXD has to be taken into account, especially within big networks. Also for RXD a series resistor of about 1kΩ can be used to smooth the edges at bit transitions. Again the additional delay within RXD has to be taken into account, if high bus speeds close to 125kbit/s are used within big networks.

4.2.5 BAT and VCC Supply Circuit

The following considerations are recommended for the power supply of the transceiver. An example circuit is illustrated in Fig 16. The battery wire contains a blocking diode (D1) to protect the ECU components against wrong supply polarity. The capacitor C4 is needed to stabilise the battery voltage. After the capacitor the wire is split into voltage regulator and transceiver supply. The latter contains a series resistor R_{BAT} for extra protection against automotive transients. The recommended range for the series resistor being attached to the supply pin BAT is 1 kΩ to 2 kΩ. The series resistance implies voltage drop on the battery supply and therefore lowers the minimum operating voltage. This voltage drop must be taken into account when determining the minimum battery operating voltage.

An additional capacitor C3 of about 10nF can be used for enhanced transient protection and for stabilising the battery voltage. It is recommended that this capacitor is connected to the BAT pin as close as possible.



Fig 16. Example of power supply circuit for the 5V device

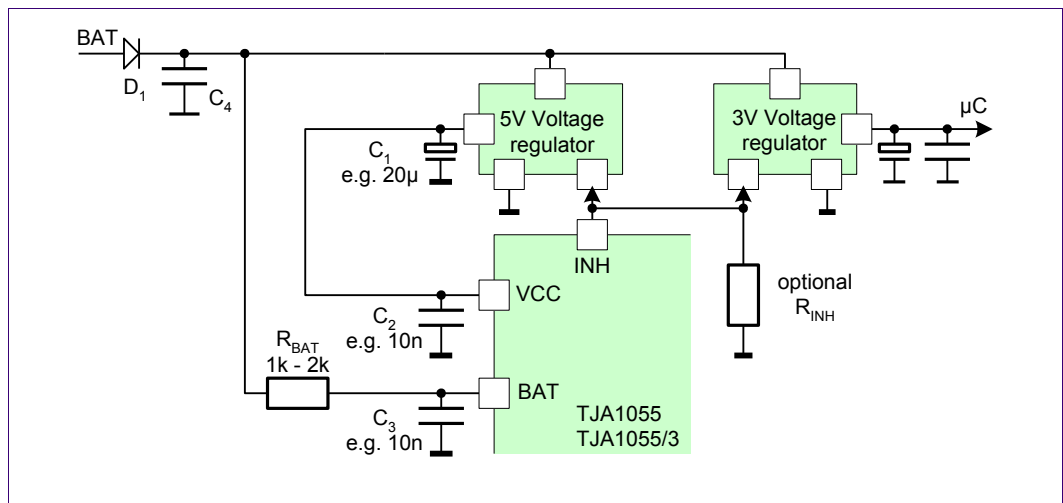


Fig 17. Example of power supply circuit for the 3V device with two voltage regulators

The voltage regulator delivers the operation current to the VCC pin of the transceiver. The VCC supply of the TJA1055T must be able to deliver current of 100mA in average for the transceiver output transmitter ($I_{CC_NORM_AVG}$, see chapter 4.2.6). Using a linear voltage regulator and to actuate the device in all conditions, it is recommended to stabilize the output voltage with a bypass capacitor C1 of about 20µF. Its purpose is to buffer disturbances on the battery line and to buffer extra supply current demand in case of bus failures. It is usually placed at the output of the voltage regulator. Typically, a second capacitor C2 is integrated close to the transceiver. The size of this capacitor should be between 10-47nF and should also be placed as close as possible to the VCC pin of the transceiver. For reliability reasons it might be useful to apply two capacitors in series connection between VCC and GND. Thus, a single shorted capacitor (e.g. damaged device) cannot short-circuit the VCC supply.

4.2.6 Current Consumption on BAT Pin

Battery Supply Current

The battery current consumption of the TJA1055T in low power mode is typical 25µA with an applied battery voltage of 14V. If there is a low battery voltage of 7V-8V the undervoltage detector of the transceiver becomes active requiring extra current to generate more accurate voltage thresholds. This improves the undervoltage detection of the TJA1055T compared to the TJA1054T. For the TJA1055T the power-on flag is set earliest at 5V and latest at 4V battery voltage. For the TJA1054T this is guaranteed between 3,5V down to 1V.

Voltage drop on Series Resistor at BAT Pin

The following considerations are recommended for the determination of the series resistor (R_{BAT}) being attached to the supply input BAT of the TJA1054T / TJA1055T transceiver products. The minimum recommended series resistance is about 1kΩ for protection against automotive transients. On the other hand the series resistance implies voltage drop on the battery supply and therefore lowers the minimum operating voltage. The voltage drop across the R_{BAT} series resistance can be calculated with the following consideration:

$$V_{DROPLPM} = R_{BAT} * (I_{BATmaxL} + I_{IL} + I_{INH} + I_{RTL})$$

$V_{DROPLPM}$	Maximum voltage drop in low power mode
R_T	Series resistor at BAT pin
$I_{BATmaxL}$	Maximum battery supply current in low power modes ($V_{BAT} = 5V$ to $40V$)
I_{IL}	WAKE input current, if $V_{WAKE_N} = 0$
I_{INH}	Maximum INH load, when used
I_{RTL}	Maximum RTL current in low power modes ($V_{RTL} = 0$)

Table 7 Example calculation of worst-case voltage drop on battery series resistor

Example values according TJA1055T datasheet Rev.03 – 13 March 2007 [2]

Example values according TJA1054T datasheet 11th February 2002 [3]

Symbol	Description	Condition	TJA1054T	TJA1055T
V_{BAT}	Operating voltage		5V – 27V	5V – 40V
I_{BAT}	Maximum battery supply current	TJA1054T: $V_{BAT} = 12V$ TJA1055T: $V_{BAT} = 14V$	50 μ A	40 μ A
$I_{BATmaxL}$	Maximum battery supply current (low-power-modes)	TJA1054T: $V_{BAT}=5V$ to 27V TJA1055T: $V_{BAT}=5V$ to 40V	125 μ A	100 μ A
I_{IL}	WAKE input current	$V_{WAKE_N} = 0V$ TJA1054T: $V_{BAT}=5V$ to 27V TJA1055T: $V_{BAT}=5V$ to 40V	10 μ A	12 μ A
I_{INH}	Maximum recommended INH load (when used)		1mA	1mA
I_{RTL}	Maximum RTL current in low power modes	Dominant: $V_{RTL} = 0$	1.25mA	1.50mA
R_T	Series resistor at BAT pin		1k Ω	1k Ω
$I_{BATTLP1}$	Maximum total battery current in low power mode	Standby Mode $T < 1.6$ ms Dominant bus $V_{WAKE_N} = 0V$	2.38mA	2.61mA
$V_{DROPLPM1}$	Maximum voltage drop in low power mode	Standby Mode $T < 1.6$ ms Dominant bus $V_{WAKE_N} = 0V$ $R_T = 1k\Omega$	2.38V	2.61V
$V_{DROPLPM2}$	Maximum voltage drop in low power mode without INH load	Standby Mode $T < 1.6$ ms Dominant bus INH not used $R_T = 1k\Omega$	1.38V	1.61V

4.2.7 Current Consumption on VCC Pin

Summary

In order to properly dimension the VCC supply of the fault-tolerant CAN transceivers two parameters have to be taken into account:

1. The average supply current
2. The peak supply current

The average supply current is needed to calculate the thermal load of the required VCC voltage regulator. The peak supply current may flow in case of certain bus failure

conditions for a certain time and thus has an impact on the power supply buffering. The VCC supply of the transceiver is recommended to support the characteristics as follows:

Table 8 Overview of supply currents:

Item	Symbol	TJA1054T	TJA1055T
Average VCC supply current without bus failures	$I_{CC2_NORM_AVG}$	41 mA	37,5 mA
Average VCC supply current at presence of single bus failures	$I_{CC3_ISC1_AVG}$	76 mA	72,5 mA
Worst case peak VCC supply current at presence of single bus failure (for 6 bit times max.)	$I_{CC3_ISC1_DOM}$	141 mA	135 mA
Worst case peak VCC supply current at presence of dual bus failures (for 17 bit times max.)	$I_{CC4_ISC2_DOM}$	142 mA	136 mA

The capacitive buffering needed for the transceiver depends on the systems power concept and the regulator characteristic of the used voltage regulator chip.

In case the transceiver has a separated VCC power supply apart from the microcontroller, the peak supply current during single bus failures is relevant because here the communication medium has to keep unaffected. The worst-case dual failure situation is not relevant since here the communication medium is completely out of operation and the transceiver does not need to be supplied anymore. Such systems are recommended to provide a bypass capacitance of 47 μ F in order to support single wiring faults. Depending on the regulator behaviour this capacitance may become smaller if the regulation time constant is fast enough.

In case the transceiver's VCC power supply is shared with its host microcontroller, the peak supply current during the worst-case dual failure situation has to be taken into account. This is because the μ C has to keep a proper supply even if there is no CAN communication possible at all. Such systems are recommended to provide a bypass capacitance of 100 μ F. Depending on the regulator behaviour this capacitance may become much smaller if the regulation time constant is fast enough.

This capacitance can be implemented as a separate component or alternatively through a corresponding increase of the capacitance of the bypass capacitor being located at the VCC voltage regulator.

In the following, relevant cases are considered in more detail.

4.2.7.1 Average Supply Current; no Bus Short-Circuit Conditions

In recessive state the different transceivers are consuming a VCC supply current as listed in the corresponding data sheets. In dominant state the VCC supply current is calculated by the addition of the IC-internal supply current (see data sheet TJA1055T: “no load” condition) and the output current at pins CANH and RTL.

The reason for taking the currents of CANH and RTL is, because CANH has an internal path to GND and is pulled to VCC in case of a dominant bit. So, the current flows from the transceiver into the network. CANL has an internal path to VCC and is pulled to GND in case of a dominant bit. Therefore the current flows from the network through the transceiver to GND. CANL still has a connection to VCC via RTL and the maximum current that can flow out of RTL through the resistor into the transceiver again is limited by the value of the resistor which is 1kOhm is the example below.

Maximum dominant supply current without bus wiring faults

The maximum dominant supply current (without bus wiring faults) can calculate by following equations.

$$I_{CC1_DOM_MAX} = I_{CC_DOM} + I_{CANH_DOM} + I_{RTL_DOM}$$

$$I_{RTL_DOM} = (V_{CC} - V_{CANL_DOM}) / R_T$$

Table 9 Maximum dominant supply current without bus wiring faults:

Item	Symbol	TJA1054T	TJA1055T
VCC supply current dominant, max, no load	I_{CC_DOM}	27 mA	21 mA
CANH dominant current	I_{CANH_DOM}	40 mA	40 mA
Assumed termination resistor	R_T	1 k	1k
Assumed CANL dominant voltage	V_{CANL_DOM}	1 V	1V

TJA1054T : $I_{CC1_DOM_MAX} 1054 = 27mA + 40 mA + (5V - 1V) / 1k = 71 mA \text{ max.}$

TJA1055T : $I_{CC1_DOM_MAX} 1055 = 21mA + 40 mA + (5V - 1V) / 1k = 65 mA \text{ max.}$

Thermal considerations without bus wiring faults

For thermal considerations the average supply current at pin VCC is relevant considering the transmit duty cycle. In the following example a continuously transmitting node is assumed. This might happen e.g. if a node starts a transmission while the rest of the network does not respond with an acknowledge for some reason. Typically a much lower duty cycle is relevant since a node transmits messages within certain time slots only, depending on the applications network management. With an assumed transmit duty cycle of 50% on pin TXD, the maximum average supply current is

$$I_{CC2_NORM_AVG} = 0.5 * (I_{CC_REC} + I_{CC1_DOM_MAX})$$

Table 10 Thermal considerations without bus wiring faults:

Item	Symbol	TJA1054T	TJA1055T
VCC supply current recessive, max.	I_{CC_REC}	11 mA	10 mA

TJA1054T : $I_{CC2_NORM_AVG} 1054 = 0.5 * (11mA + 71mA) = 41 mA \text{ max.}$

TJA1055T : $I_{CC2_NORM_AVG} 1055 = 0.5 * (10mA + 65mA) = 37,5 mA \text{ max.}$

Average supply current; with a short-circuit of one bus wire

The maximum VCC supply current occurs with a bus wire short-circuit between CANH and GND. In this case the CANH outputs a maximum short circuit current in dominant state (see data sheets). For thermal considerations the average supply current is relevant. For buffering considerations the maximum dominant supply current is relevant.

Maximum dominant supply current with CANH shorted to GND

$$I_{CC3_SC1_DOM} = I_{CC_DOM} + I_{O(CANH)_DOM} + I_{RTL_DOM} \quad (t \leq 6 \text{ bit times})$$

The 6-bit time limitation is caused by a supposed Error Flag to be sent by the CAN Controller.

Table 11 Maximum dominant supply current with CANH shorted to GND:

Item	Symbol	TJA1054T	TJA1055T
CANH dominant output current, short circuit	$I_{O(CANH)_DOM}$	110 mA	110 mA

TJA1054T : $I_{CC3_SC1_DOM} 1054 = 27\text{mA} + 110 \text{ mA} + (5\text{V} - 1\text{V}) / 1\text{k} = 141 \text{ mA max.}$

TJA1055T : $I_{CC3_SC1_DOM} 1055 = 21\text{mA} + 110 \text{ mA} + (5\text{V} - 1\text{V}) / 1\text{k} = 135 \text{ mA max.}$

Thermal considerations with CANH shorted to GND

For thermal considerations the average supply current at pin VCC is relevant considering the transmit duty cycle. With a transmit duty cycle of 50% on pin TXD, the maximum average supply current at CANH to GND short-circuit is:

$$I_{CC3_SC1_AVG} = 0.5 * (I_{CC_REC} + I_{CC3_SC1_DOM})$$

Thermal considerations with CANH shorted to GND:

TJA1054T : $I_{CC3_SC1_AVG} 1054 = 0.5 * (11\text{mA} + 141\text{mA}) = 76 \text{ mA max.}$

TJA1055T : $I_{CC3_SC1_AVG} 1055 = 0.5 * (10\text{mA} + 135\text{mA}) = 72,5 \text{ mA max.}$

VCC extra supply current in single fault condition

Compared to the quiescent current in recessive state the maximum extra supply current when the CANH driver is turned on with CANH shorted to GND is needed to calculate the required worst case VCC buffer capacitance. This extra supply current has to be buffered for up to 6 bit times, depending on the applications voltage regulator.

$$\Delta I_{CC3_SC1} = I_{CC3_SC1_DOM} - I_{CC_REC_MIN}$$

Table 12 VCC extra supply current in case of single fault condition:

Item	Symbol	TJA1054T	TJA1055T
Min VCC supply current, recessive	$I_{CC_REC_MIN}$	4 mA	2,5 mA

TJA1054T : $\Delta I_{CC3_SC1} 1054 = 141 \text{ mA} - 4 \text{ mA} = 137 \text{ mA max.}$

TJA1055T : $\Delta I_{CC3_SC1} 1055 = 135 \text{ mA} - 2,5 \text{ mA} = 132,5 \text{ mA max.}$

4.2.7.2 Worst Case Max VCC Supply; with a Dual Short Circuit

The worst-case max. VCC supply current is flowing in case of a dual short-circuit of the bus lines CAN_H and CAN_L to ground. In this case no communication is possible. Nevertheless the application supply should be able to deliver a proper VCC for the microcontroller in order to prevent faulty operation.

If there is a separate voltage regulator available supplying the transceiver exclusively, no care has to be taken on this dual short circuit condition since the transceivers are behaving fail safe in case of under voltage conditions and the μC is still powered properly by its own supply.

In case of a shared voltage supply of transceiver and microcontroller this dual fault condition is relevant to dimension the required buffer capacitor.

Max VCC supply current in worst case dual fault condition

$$I_{CC4_ISC2_DOM} = I_{CC_DOM} + I_{O(CANH)_DOM} + I_{RTL_ISC_DOM} \quad (t \leq 17 \text{ bit times})$$

$$I_{RTL_ISC_DOM} = V_{CC} / R_T \quad (8)$$

The 17-bit time limitation is caused by the CAN protocol. Due to the dual fault condition with CANH and CANL shorted to GND the pin RXD of the transceiver is continuously clamped recessive (CANL to GND forces CANH operation; CANH is clamped recessive).

The moment the CAN controller starts a transmission; this dominant Start Of Frame bit is not feed back via RXD and thus forces an error flag due to the bit failure condition (TXD Error Counter incremented by 8). This first bit of the error flag again is not reflected at RXD and forces the next error flag (TXD Error Counter + 8).

Latest after 17 bit times, depending on the TX Error Counter Level before starting this transmission, the CAN controller reaches the Error Passive limit (128) and stops sending dominant bits. Now a sequence of 25 recessive bits follows (8 Bit Error Delimiter + 3 Bit Intermission + 8 Bit Suspend Transmission) and the VCC current becomes reduced to the recessive one. From now on only single dominant bits (Start Of Frame) followed by 25 recessive bits (Passive Error Flag + Intermission + Suspend Transmission) are output until the CAN controller enters the Bus Off State. So, for dimensioning the VCC voltage source in this worst case dual failure scenario, up to 17 bit times might have to be buffered by a bypass capacitor depending on the regulation capabilities of the used voltage supply.

Max VCC supply current in worst case dual fault condition:

TJA1054T : $I_{CC4_ISC2_DOM} 1054 = 27 \text{ mA} + 110 \text{ mA} + 5V / 1k = 142 \text{ mA max.}$

TJA1055T : $I_{CC4_ISC2_DOM} 1055 = 21 \text{ mA} + 110 \text{ mA} + 5V / 1k = 136 \text{ mA max.}$

4.2.7.3 VCC extra supply current in dual fault condition

Compared to the quiescent current in recessive state the maximum extra supply current when the CANH driver is turned on in dual short-circuit condition is needed to calculate the required worst case VCC buffer capacitance. This extra supply current has to be buffered for that time the applications voltage regulator needs to react.

$$\Delta I_{CC4_SC2} = I_{CC4_SC2_DOM} - I_{CC_REC}$$

VCC extra supply current in case of dual fault condition:

Table 13 VCC extra supply current in case of single fault condition

Item	Symbol	TJA1054T	TJA1055T
Min VCC supply current, recessive	I_{CC_REC}	4 mA	2,5 mA

TJA1054T : $\Delta I_{CC4_SC2\ 1054} = 142\text{ mA} - 4\text{ mA} = 138\text{ mA max.}$

TJA1055T : $\Delta I_{CC4_SC2\ 1055} = 136\text{ mA} - 2,5\text{ mA} = 133,5\text{ mA max.}$

4.2.7.4 Calculation of worst-case bypass capacitor

Depending on the power supply concept, the required worst-case bypass capacitor can be calculated. In case of a separate VCC supply for the transceiver only, the extra supply current ΔI_{CC3_SC1} in case of the single fault condition has to be taken with a maximum of 6 dominant bit times (length of error frame).

If the transceiver and the host microcontroller are supplied from the same regulator (shared VCC supply), the extra supply current ΔI_{CC4_SC2} in case of the dual fault condition has to be taken with a maximum of 17 dominant bit times.

$$C_{BUFF} = \Delta I_{CCx_SCx} * t_{DOM_MAX} / \Delta V_{MAX}(10)$$

The capacitor C_{BUFF} is needed if the voltage regulator is not able to deliver any extra current within the maximum dominate output drive t_{DOM_MAX} during the dual fault condition.

Example calculation, separate supplied transceiver @ 83,33kBit/s

In case of a separate transceiver supply the bypass capacitance has to be calculated based on the single fault condition with CANH shorted to GND. Here the dual fault is not relevant.

Assumption of 83,33 kBit/s: $t_{DOM_MAX} = 6 * 12\text{ us} = 72\text{ us}$

Maximum allowed V_{CC} voltage drop: $\Delta V_{MAX} = 0.25\text{V}$

TJA1054T : $C_{BUFF\ 1054} = 137\text{ mA} * 72\text{ us} / 0.25\text{ V} = 39,5\text{ }\mu\text{F}$

TJA1055T : $C_{BUFF\ 1055} = 132,5\text{ mA} * 72\text{ us} / 0.25\text{ V} = 38,2\text{ }\mu\text{F}$

In this example the bypass capacitance to be reserved for the VCC supply of the TJA1055T transceiver is recommended to be 39,9 μF minimum at 83,33 kBit/s. It may

become smaller, if the used voltage regulator is able to deliver an extra current within t_{DOM_MAX} .

Example calculation, shared supply

In case of a shared supply concept the bypass capacitance has to be calculated based on the worst-case dual fault condition in order to keep the μC supply stable:

Assumption of 83,33 kBit/s: $t_{DOM_MAX} = 17 * 12 \text{ us} = 204 \text{ us}$

Maximum allowed V_{CC} voltage drop: $\Delta V_{MAX} = 0.25V$

TJA1054T : $C_{BUFF\ 1054} = 138 \text{ mA} * 204 \text{ us} / 0.25 \text{ V} = 113 \text{ }\mu F$

TJA1055T : $C_{BUFF\ 1055} = 133,5 \text{ mA} * 204 \text{ us} / 0.25 \text{ V} = 109 \text{ }\mu F$

In this example the bypass capacitance to be reserved for the VCC supply of the transceiver is recommended to be 114 μF minimum at 83,33 kBit/s. It may become smaller, if the used voltage regulator is able to deliver an extra current within t_{DOM_MAX} .

4.3 Application Example: Wake-up via RXD / ERR_N without VCC

There are application cases where the microcontroller stays powered all time while the transceiver becomes unpowered on VCC side in order to save some power dissipation. In order to wake-up the microcontroller through the transceiver it is required to signal a wake-up towards the microcontroller through the typical interface RXD and ERR_N. For applications based on the TJA1054T it was not possible to wake-up the system through RXD and ERR_N while VCC was off.

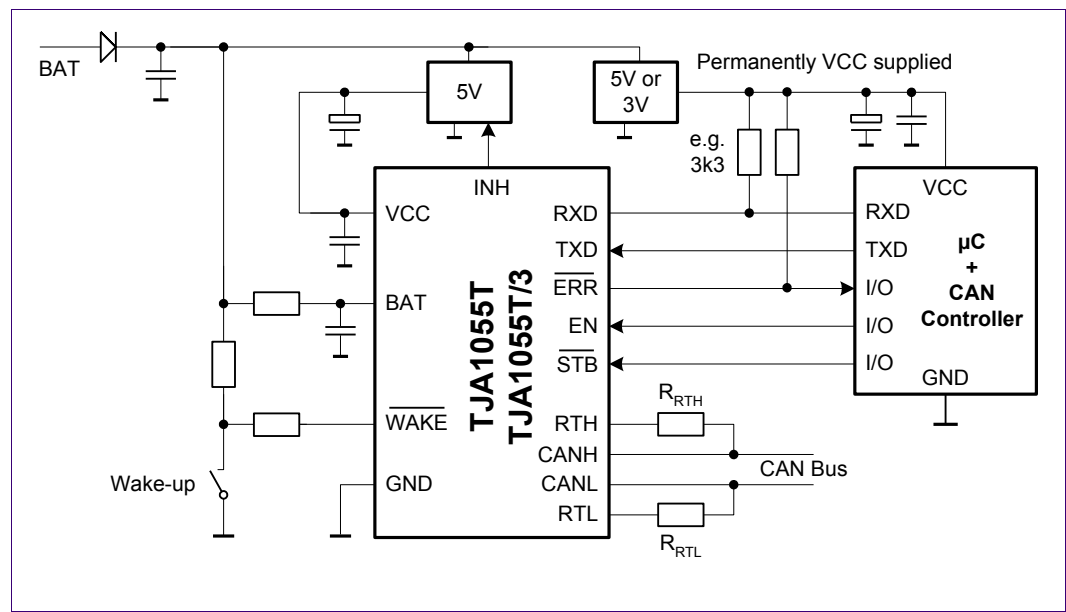


Fig 18. Example of application circuit with different supply of μC and Transceiver

In the application case shown in Fig 18 the TJA1055T provides a new feature compared to the TJA1054T. The TJA1055T is able to signal a wake-up on RXD and ERR_N even if the VCC of the transceiver is switched off.

4.3.1 Application Description

In the above example, the microcontroller is supplied permanently out of a 3V or 5V voltage regulator. RXD and ERR_N have a pull-up resistor to the μ C voltage supply. The 5V supply of the transceiver is switched off in low-power mode. For the TJA1055T the pins RXD and ERR_N are not following the VCC supply voltage towards low level with VCC off. This feature makes it possible to wake-up the supplied microcontroller through an unsupplied (VCC off, but BAT on) transceiver via RXD and ERR_N. For additional information see next chapter.

In case a TJA1054T becomes un-powered, the pins RXD and ERR_N are actively going to low level due to the pin-internal diode structures. Consequently a TJA1054T cannot signal a wake-up on RXD and ERR_N with VCC off, because the pins are already low while VCC is off.

For applications, which do not use this feature, there is no difference. It just offers some more freedom in the ECU design. So, there is no issue with drop-in replacement of the TJA1054T.

4.3.2 Wake-up capability of the TJA1055T with VCC off

The RXD and ERR_N pins of the TJA1055T have a reverse current protection diode in their VCC path (see Fig 19). This allows connecting these pins with pull-up resistors to the supply voltage of the microcontroller in order to prevent the floating behaviour of the pins when the transceiver becomes un-powered. In Normal Mode the diode is bypassed to remove the voltage drop.

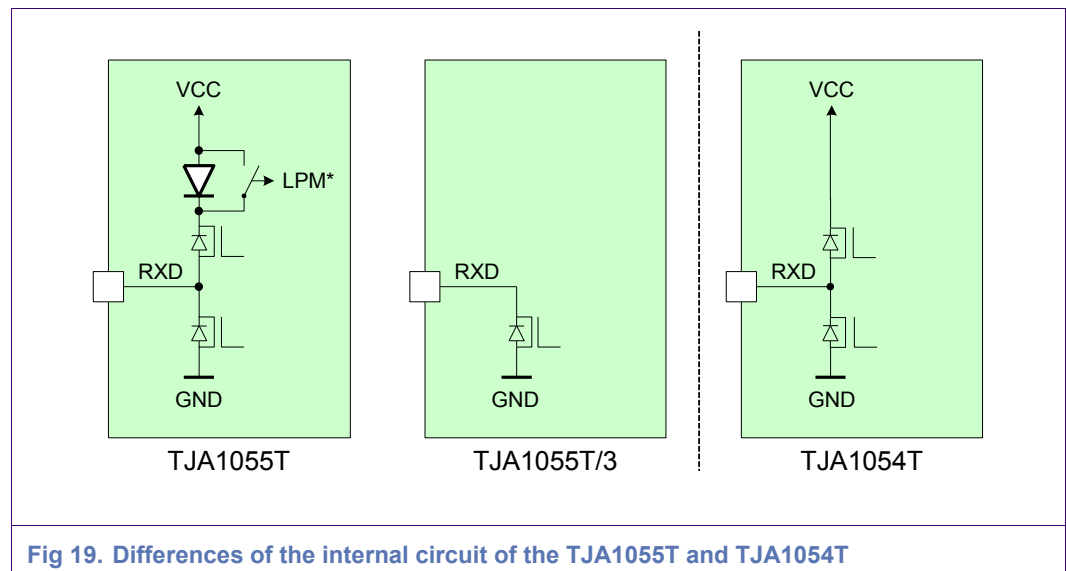


Fig 19. Differences of the internal circuit of the TJA1055T and TJA1054T

For the 3V version of the TJA1055T the VCC path is not integrated. So the TJA1055T/3 provides also the wake-up capability with VCC off.

5. Software Design

5.1 Operation Mode Control

5.1.1 Overview

The transceiver is controlled via mode pins EN and STB_N. These pins are transceiver input pins and are connected to the host microcontroller. Only the microcontroller is able to change the operating modes of the transceiver. The transceiver is powered directly from the battery supply via the pin BAT. This allows disabling the VCC supply entirely during time phases, the CAN bus is not required by the system.

The TJA1055T provides one normal operating mode and four low-power modes. The Table 14 gives an overview of the operating modes of the FT-CAN transceiver.

Table 14 Overview of operation modes

Modes	EN	STB_N	Description
Normal Mode	1	1	Normal transceiver operation
Go-to-Sleep	1	0	Switches off the INH pin after a certain time out to disable the external voltage regulator
Standby / Sleep	0	0	In Standby the INH pin is on In Sleep the INH pin is off
Power-on Standby	0	1	Allows to read back the Power-on flag

In case of VCC undervoltage condition the transceiver switches automatically into forced standby mode (except during Sleep Mode). The transceiver keeps this forced standby mode until the VCC undervoltage condition is left.

For wake-up purposes a battery-related WAKE_N pin is provided. In addition to bus failure information and the CAN received bit stream, the pins ERR_N and RXD are used to signal wake-up requests towards the application controller.

5.1.2 Normal Mode (1' 1')

The Normal Mode is entered setting STB_N=1 and EN=1 (1' 1'). During Normal Mode the INH pin is active high and the transceiver is used to transmit data to the bus and to receive data from the CAN bus. The digital input bit stream at TXD is transferred into the corresponding analog bus signal at CANH and CANL. Simultaneously, the analog bus signal is monitored and converted into the corresponding digital bit stream at RXD. In this mode the pin ERR_N is used to readout bus failure conditions with an active LOW behaviour.

Table 15 Description of applied pin value in Normal Mode

VBAT=12V, VCC=5V and GND=0V

PIN	STATE	Description of applied pin value
INH	HIGH	An external connected voltage regulator is enabled
EN	HIGH	Transceiver is in Normal only if EN and STB_N are HIGH
STB_N	HIGH	
TXD	HIGH	Recessive transmit data
	LOW	Dominant transmit data
RXD	HIGH	Recessive received data
	LOW	Dominant received data
ERR_N	HIGH	No error occur
	LOW	Error flag is signaled
CANL	VCC	Recessive bus signal
	1,4V to GND	Dominant bus signal
CANH	GND	Recessive bus signal
	VCC to 3,6 V	Dominant bus signal

5.1.3 Low-power Mode: Go-to-Sleep (0' 1')

The low-power mode Go-to-Sleep is a command to set the transceiver into Sleep Mode. Entering Go-to-Sleep the transceiver immediately changes into low-power operation, while the pin INH still keeps active HIGH for a certain time. Entering Go-to-Sleep an internal wake-up flip-flop is output via the pins RXD and ERR_N, if VCC is present. Thus both signals can be used to wake-up the application with an active low signal. If the Go-to-Sleep state keeps present for a certain time (5...50µs; see data sheet TJA1055T: — $t_{d(sleep)}$ delay time to sleep) the INH output of the TJA1055T becomes “floating” disabling the externally connected voltage regulator. Once the 50us Go-to-Sleep command time is passed, it is recommended to set EN actively to LOW level under software control. The Sleep Mode shall be activated before VCC has fallen below 4V in order to enter Sleep Mode successfully (see also Fig 20 and Fig 29). In case the Sleep Mode transition is not performed actively with $VCC \geq 4V$, there might be a slightly increased sleep current consumption (45µA instead of 25µA).

Table 16 Description of applied pin value in Low-power Mode: Go-To-Sleep
VBAT=12V, VCC=5V and GND=0V

PIN	STATE	Description of applied pin value
INH	HIGH	$t < T_{react(Sleep)}$
	Float	$t > T_{react(Sleep)}$
EN	HIGH	Transceiver is in Go-To-Sleep Mode only if EN = HIGH and STB_N = LOW
STB_N	LOW	
TXD	X	Don't care
RXD	HIGH	No wake-up signal is detected
	LOW	Wake-up signal is detected
ERR_N	HIGH	No wake-up signal is detected
	LOW	Wake-up signal is detected
CANL	VBAT	Bus idle value
CANH	GND	Bus idle value

Timings for a valid Go-To-Sleep Command

The Go-to-Sleep filter timer of the transceiver is specified in a range of 5µs up to 50µs (see datasheet TJA1055T: $t_{d(sleep)}$ delay time to sleep). That means that a Go-to Sleep command shorter than 5µs is ignored and a command longer than 50µs by guarantee will disable the INH pin and the transceiver will enter Sleep Mode. To guarantee a successful mode transition under all conditions, the maximum specified time for Go-to-Sleep command must be applied on the mode pins.

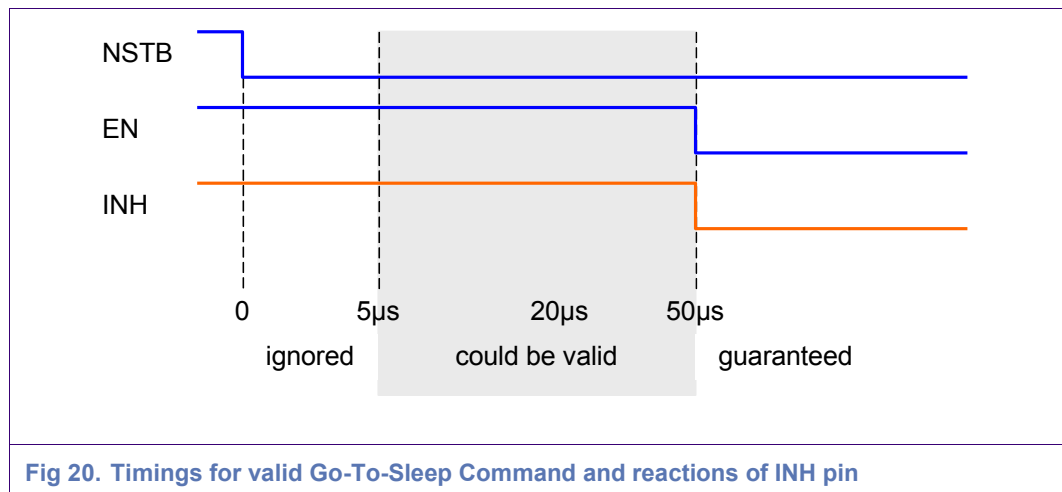


Fig 20. Timings for valid Go-To-Sleep Command and reactions of INH pin

5.1.4 Low-power Mode: Standby / Sleep (0' 0')

The Standby or Sleep Mode is entered setting STB_N=0 and EN=0. The internal “sub-modes” Standby and Sleep are distinguished only by the state of the pin INH. In Standby Mode the INH pin remains active and the external voltage regulator stays alive, this mode can be entered directly from Normal Mode. The Sleep Mode is entered with a previous successful Go-to-Sleep procedure. During Sleep Mode the pin INH is floating and switches off an external voltage regulator. During Standby or Sleep Mode the pins RXD and ERR_N are signaling a possible wake-up condition (see Table 17 and chapter 5.2). A wake-up is caused by an edge event at WAKE_N pin or via CAN bus traffic.

ATTENTION: A mode transition to any other mode via mode control pins EN and STB_N is only possible if supply voltage VCC is present. In Sleep Mode the INH pin and the external voltage regulator is switched off, so VCC is also off. A received wake-up event activates the pin INH again and thus VCC.

Table 17 Description of applied pin value in Low-power Mode: Standby / Sleep
VBAT=12V, VCC=5V / 0V and GND=0V

PIN	STATE	Description of applied pin value
INH	HIGH	Standby: An external connected voltage regulator is enabled
	Float	Sleep: A external connected voltage regulator is disabled
EN	LOW	Transceiver is in Standby or Sleep Mode only if EN and STB_N are both LOW
STB_N	LOW	
TXD	X	Don't care
RXD ¹	HIGH	No wake-up signal is detected
	LOW	Wake-up signal is detected
ERR_N ⁴	HIGH	No wake-up signal is detected
	LOW	Wake-up signal is detected
CANL	VBAT	Bus idle value
CANH	GND	Bus idle value

4. The TJA1055 allows keeping RXD and ERR_N on high level, even if VCC is switched off. This can be achieved with an external pull-up to the VCC supply of the microcontroller (e.g. via the internal pull-up of the corresponding I/O port). Thus, even without VCC present, a wake-up can be signaled with an active LOW signal.
 This is in contrast to the TJA1054T(A) which always pulls these pins to LOW level with VCC off due to internal diodes to VCC.

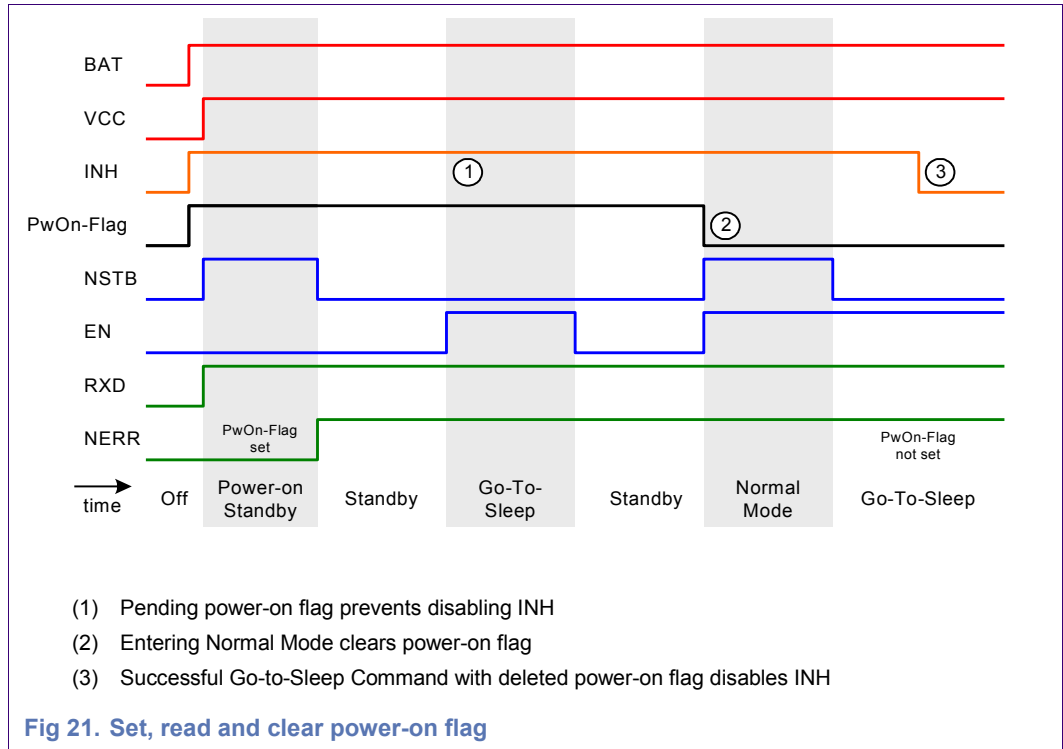
5.1.5 Low-power Mode: Power-on Standby (1' 0')¹

The Power-on Standby Mode is entered setting STB_N=1 and EN=0. This mode behaves similar to Standby Mode (see above) with the difference that the pin ERR allows reading back the internal PWON flag. This flag is set whenever the transceiver is powered with battery supply the first time or after BAT undervoltage detection. So the application can distinguish between a cold start situation caused by a system sleep or a cold start due to first battery connection of the device. The meaning of the pins in that mode is summarized in Table 18.

Table 18 Description of applied pin value in Low-power Mode: Power-on Standby
VBAT=12V, VCC=5V and GND=0V

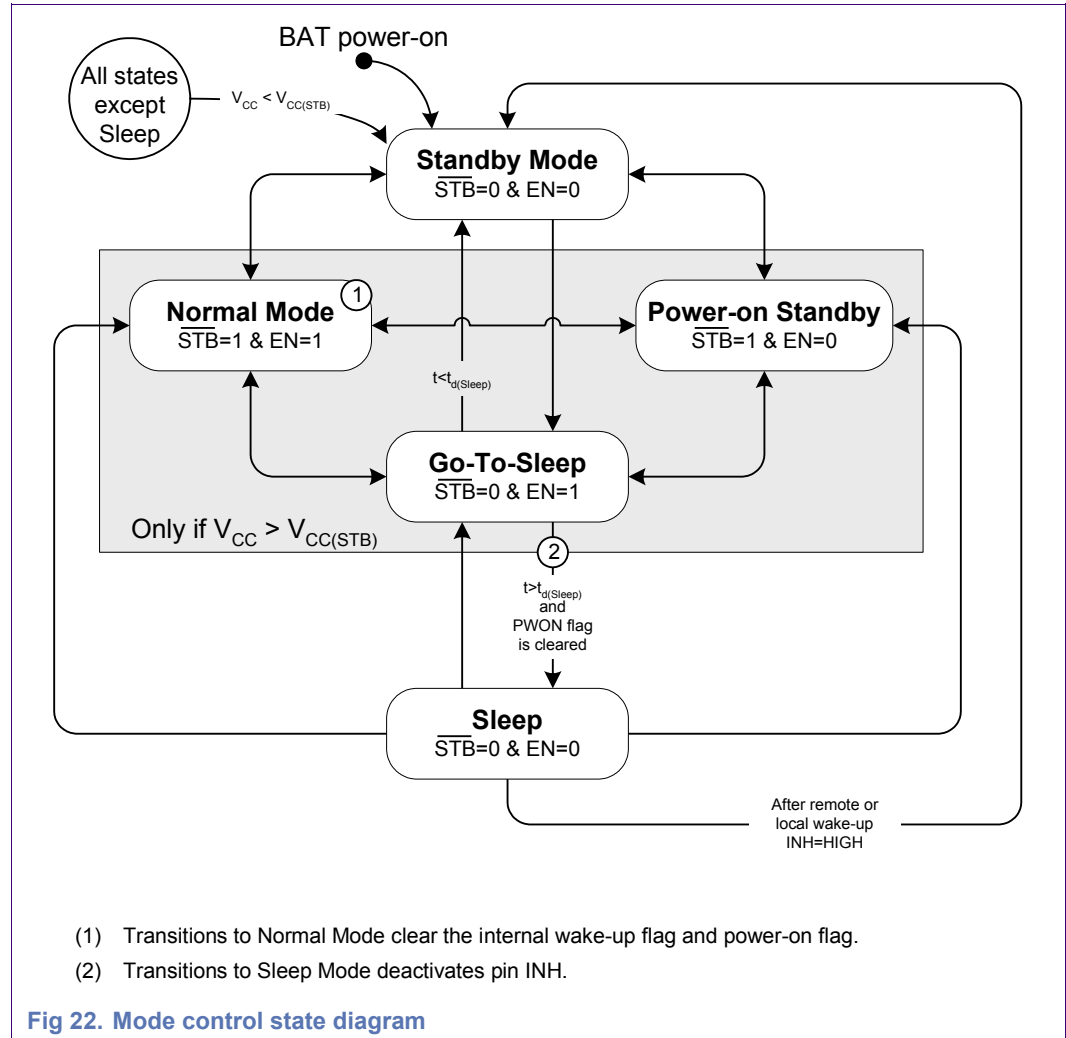
PIN	STATE	Description of applied pin value
INH	HIGH	An external connected voltage regulator is enabled
EN	LOW	Transceiver is in Power-on Standby Mode only if EN = LOW and STB_N = HIGH
STB_N	HIGH	
TXD	X	Don't care
RXD	HIGH	No wake-up signal is detected
	LOW	Wake-up signal is detected
ERR_N	HIGH	No power-on event
	LOW	Power-on event detected
CANL	VBAT	Bus idle value
CANH	GND	Bus idle value

The power-on flag is set with VBAT falling below Vpof(BAT) (see [2]: power-on flag voltage on pin BAT). This flag has the highest priority and locks the transceiver from entering sleep mode. To delete the power-on flag the transceiver has to enter the normal mode once for at least 500ns (see also Fig 21).



5.1.6 State Diagram

The two control pins STB_N and EN coming from the host microcontroller are used to control the actual mode of operation like normal mode or any of the low-power modes.



Note, that a change from the power-on condition (STB_N and EN = -Ø) is possible only, if the VCC supply is present. Whenever VCC falls below a certain level (see data sheet TJA1055T [2]: -supply voltage for forced Standby Mode) the fail-safe Forced Standby Mode is entered automatically (power-fail). Depending on the selected mode of operation, the I/O pins RXD and ERR_N provide different information for the application as described within the previous chapters.

5.2 Internal Flag Signaling

5.2.1 Power-on Flag

The Power-on (PWON) flag is set whenever the transceiver is supplied the first time or the battery voltage drops below a certain limit (see [2]: “power-on flag voltage on pin BAT”). In order to readout the PWON flag the Power-on Standby Mode is used. This flag is only cleared when entering the Normal Mode.

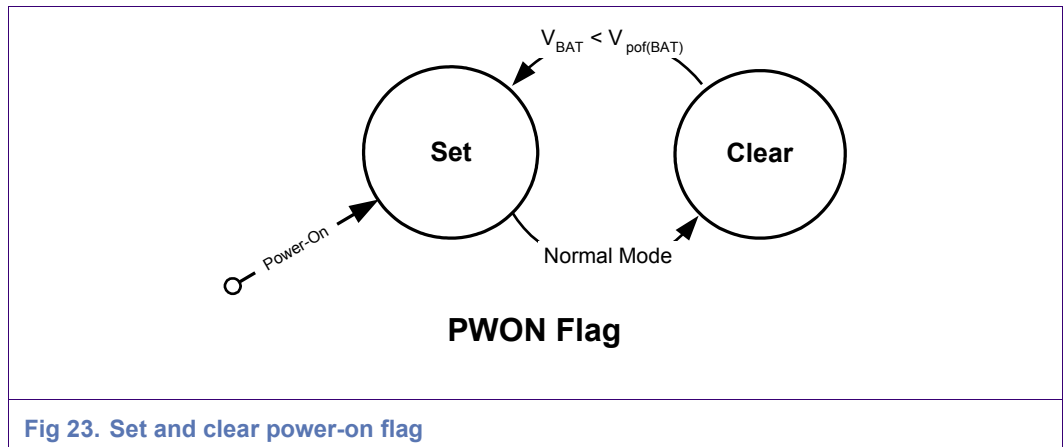


Fig 23. Set and clear power-on flag

Note: With a pending PWON flag the transceiver cannot enter Sleep Mode!

5.2.2 Wake-up Flag

An internal wake-up flag is set upon a local or remote wake-up event. This flag is cleared whenever the Normal Mode is entered via STB and EN. The content of this flag is signaled via RXD and ERR_NERR_N according to the corresponding state diagrams.

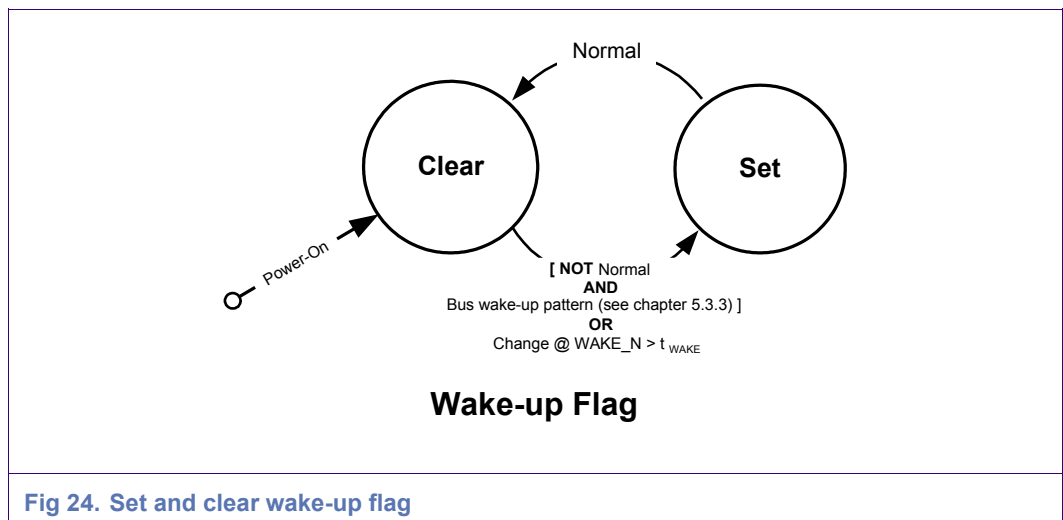


Fig 24. Set and clear wake-up flag

5.2.3 Error-Flag

The error flag is set if a bus error condition occurs. This flag is signaled via pin ERR_N in Normal Mode only. A state transition to Low-power Mode will not clear the internal error flag. Clearing this flag is only possible if the applied bus error is removed. For further information about pin interpretation see chapter 9.2.

5.2.4 INH / RXD / ERR_N Pin Behaviour and Flag Signalling

During Normal Mode the pin RXD reflects the actual bus signal. Immediately with changing into one of the low power modes, the content of the internal Wake-up Flag is reflected at pin RXD. The TJA1055T isn't pulling down the RXD and ERR_N pins to LOW with VCC off. This allows keeping RXD and ERR_N on high level with an external pull-up to the VCC supply of the microcontroller (see also chapter 4.3). A wake-up condition is signalled active LOW. (See Fig 25)

The pin ERR_N is used to signal bus failure conditions during normal operation with an active LOW behaviour. As soon as the transceiver is switched into Go-To-Sleep or Standby Mode the internal Wake-up Flag is reflected via ERR_N similar to the pin RXD. A change towards Power-on Standby switches ERR_N to the internal PWON Flag, immediately. A power-on condition is signalled active LOW. Please take care that the external loading to the pin ERR_N may cause a delay changing the level from LOW to HIGH. Typically a microcontroller port pin causes a load of some 10pF to the pin ERR_N. Due to the relatively weak pull-up behaviour of the pin ERR_N, charging this wire may need relevant time for fast operating software. (See Fig 25)

The pin INH is controlled by the Go-To-Sleep state and the wake-up events. There is a priority of wake-up in order to make sure that any wake-up event keeps the external voltage regulator active independently of a Go-To-Sleep command. Note that a successful Go-To-Sleep is possible only if the Normal Mode was entered once after a power-on condition. The PWON flag has to be cleared making sure that the system was started successfully before entering the Sleep Mode the first time. (See Fig 25)

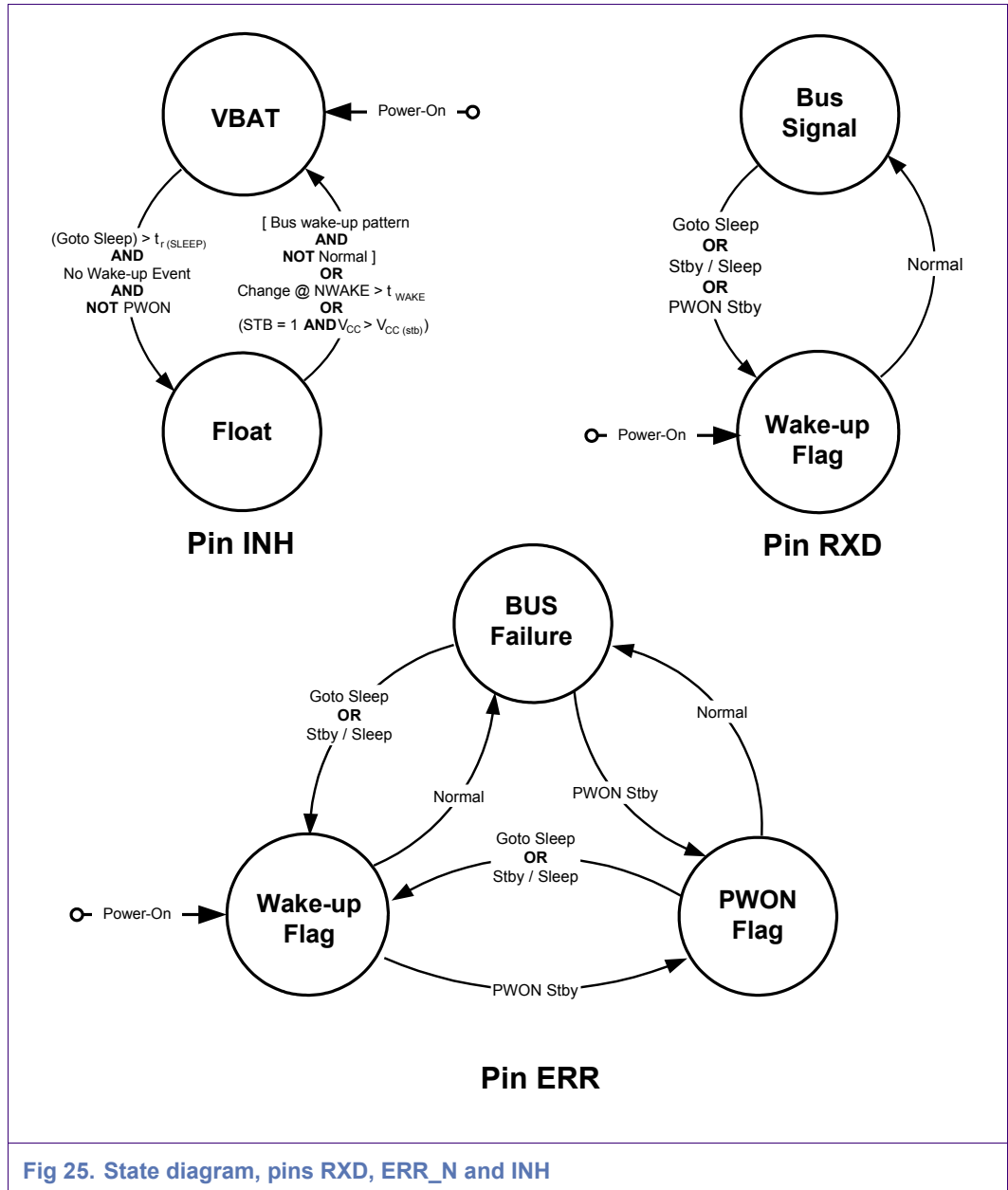


Fig 25. State diagram, pins RXD, ERR_N and INH

5.3 System Wake-up

5.3.1 Wake-up Overview

Once the transceiver is not within Normal Mode there are the following possibilities to wake-up the system:

- Local wake-up using the local pin WAKE
- Remote wake-up caused by CAN bus traffic
- Mode change entering Normal Mode via STB and EN

5.3.2 Local wake-up

A local wake-up can be forced with an edge at the pin WAKE_N of the transceiver. A positive edge as well as a negative edge results in a system wake-up if the signal keeps constant for a certain time (see [2]: “required time on pin WAKE_N for local wake-up”). Thus short spikes are filtered and do not result in unwanted system wake-up conditions.

As a result of the edge at pin WAKE_N, the internal wake-up flip-flop is set and output at ERR_N and RXD active low. Additionally the pin INH becomes HIGH again, starting the external voltage regulator.

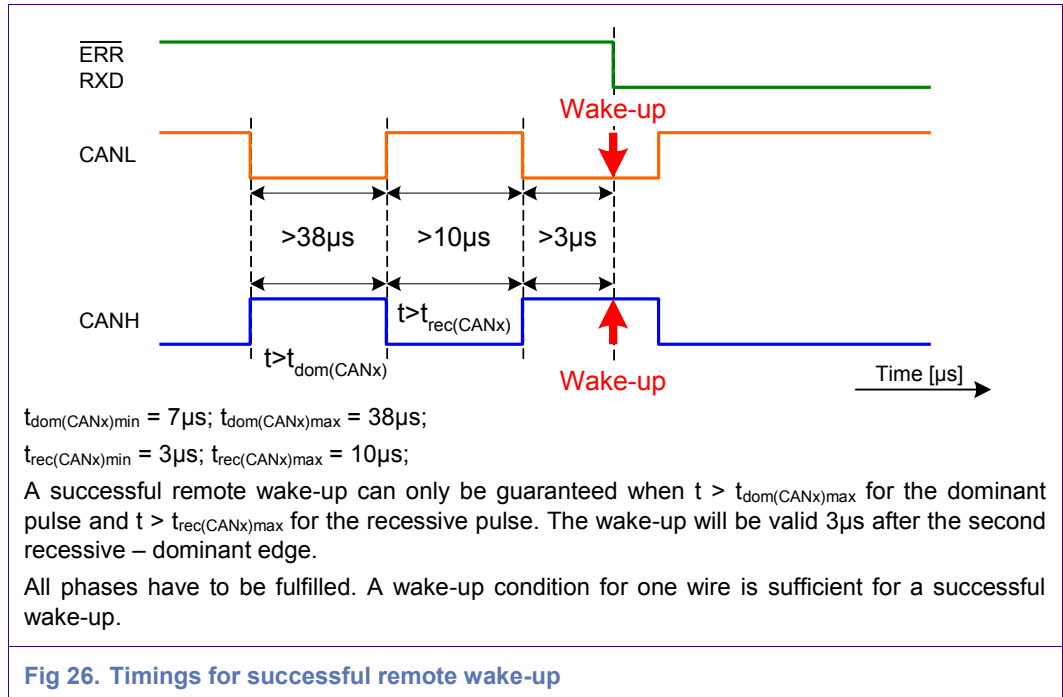
Note that the pin WAKE_N provides an internal weak pull-up current towards battery in order to provide a defined condition in case of open circuit.

5.3.3 Remote wake-up

In order to wake-up the TJA1055T via the bus lines a CAN message with certain dominant and recessive phases is required (see Fig 26). The remote wake-up is possible on each CAN line, because CANH and CANL are evaluated separately (single ended).

Whenever the bus becomes dominant for a certain time within a CAN message (see [2]: “dominant time for remote wake-up on pin CANH or CANL”) the internal wake-up flip-flop is set and the pin INH activates the external voltage regulator.

The CAN message that wakes a node out of low power usually cannot be received by this node, because the transceiver does not forward the bit stream towards the CAN protocol controller of the microcontroller. Instead the transceiver monitors the bus for a wake-up condition signaling a successful wake-up permanently on RXD and ERR_N. The reaction time needed to become ready-to-receive depends on the node software and how long the microcontroller needs to activate the CAN controller setting the transceiver into Normal Mode.



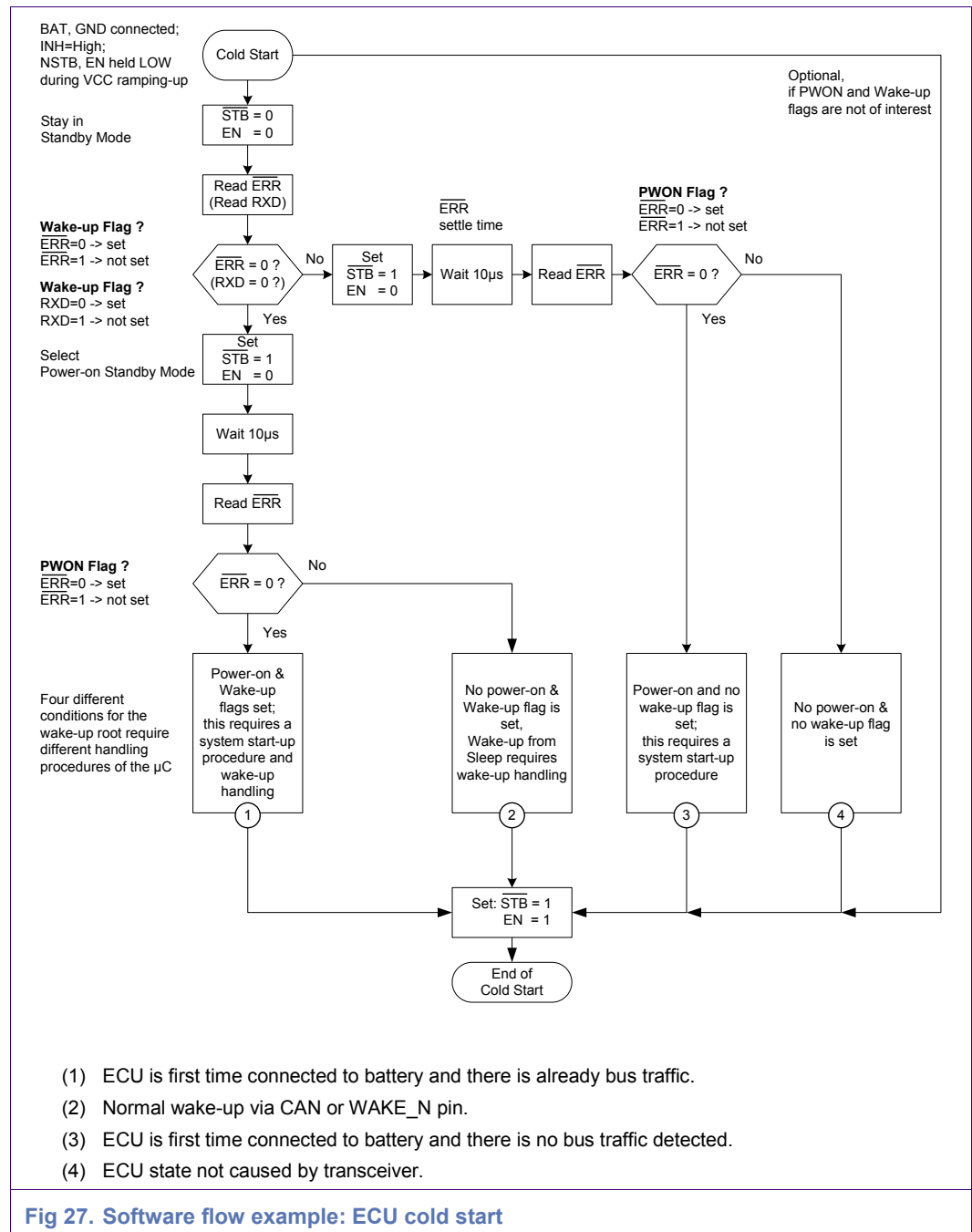
5.3.4 Host Wake-up (Mode change)

The connected host microcontroller can directly switch the transceiver into Normal Mode by setting STB_N and EN HIGH in case the VCC supply is present at the transceiver and the microcontroller.

5.4 Flow Charts

5.4.1 Example: ECU Cold Start

A cold start of an ECU happens whenever the microcontroller and the transceiver are supplied at VCC the first time. This state is caused by a wake-up from Sleep Mode or by the first battery supply (BAT power-on). In the following Fig 27 suggested software flow-chart for the start-up procedure is shown. It is recommended that the microcontrollers feature a weak pull-down or a floating behaviour on their port pins during power-up. The TJA1055T comes up in Standby Mode after first battery connection. That is important for a controlled start-up to read out the wake-up or power-on flag.



In case battery power is applied for the first time, an internal hardware reset signal is given to the transceiver for initialization. Subsequently the PWON flag is set and the pin INH is pulled to V_{BAT} , activating the voltage regulator(s) and ramping up the VCC supply. If VCC is present the microcontroller assumes control and sets or keeps the transceiver in standby mode and reads the pin ERR_N or RXD.

If a LOW signal is signaled on pin ERR_N or pin RXD the wake-up flag is set. If there is a HIGH level on ERR_N or RXD no local or remote wake-up was applied.

After reading out the wake-up flag the transceiver is set to power-on standby mode in order to read the power-on flag. A LOW-level signal is displayed on pin ERR_N that indicates a power-on event. If there is a HIGH level signaled on ERR_N no power-on has happened.

Depending on the internal flags four different conditions for the wake-up of the microcontroller and transceiver are possible and the dedicated handling procedure could start.

5.4.2 Start-up from Standby Mode

In Standby Mode the VCC power supply of the microcontroller and the transceiver is active. The microcontroller and the transceiver are in low power mode. If the transceiver receives a wakeup either via the bus or via the pin WAKE_N, the internal wakeup flag is set and signalled at the pin ERR_N and RXD. These signals can be used for wakeup of the microcontroller from its power-down mode with e.g. an interrupt handling routine. The starting application program can now take over the control of the transceiver.

As the microcontroller remains powered by the VCC supply, the microcontroller can monitor its port pins for possible wakeup events. Upon detection of a wakeup event the microcontroller can initiate a wakeup by forcing the transceiver directly into Normal Mode. Here reading the PWON flag is not necessary.

5.4.3 Example: How to enter Standby Mode

When the network management decides to put the bus system into Standby Mode, each transceiver must receive an appropriate standby command. The flow diagram seen in Fig 28 shows the different steps in order to put the TJA1055T into Standby Mode.

Upon receiving a standby command (e.g. using a certain CAN message) the microcontroller has to stop all CAN transmission. In order to ensure that no CAN communication is present on the bus any more, caused by other nodes, a user defined silent time is recommended before the TJA1055T is put into Standby Mode by selecting STB_N=0 and EN=0. If there would be no system dependent –silent time” implemented there would be the risk that a node sends out a last message while another one is already on the way towards Standby Mode. This would cause a wakeup event thus making it impossible to enter a system wide low-power state.

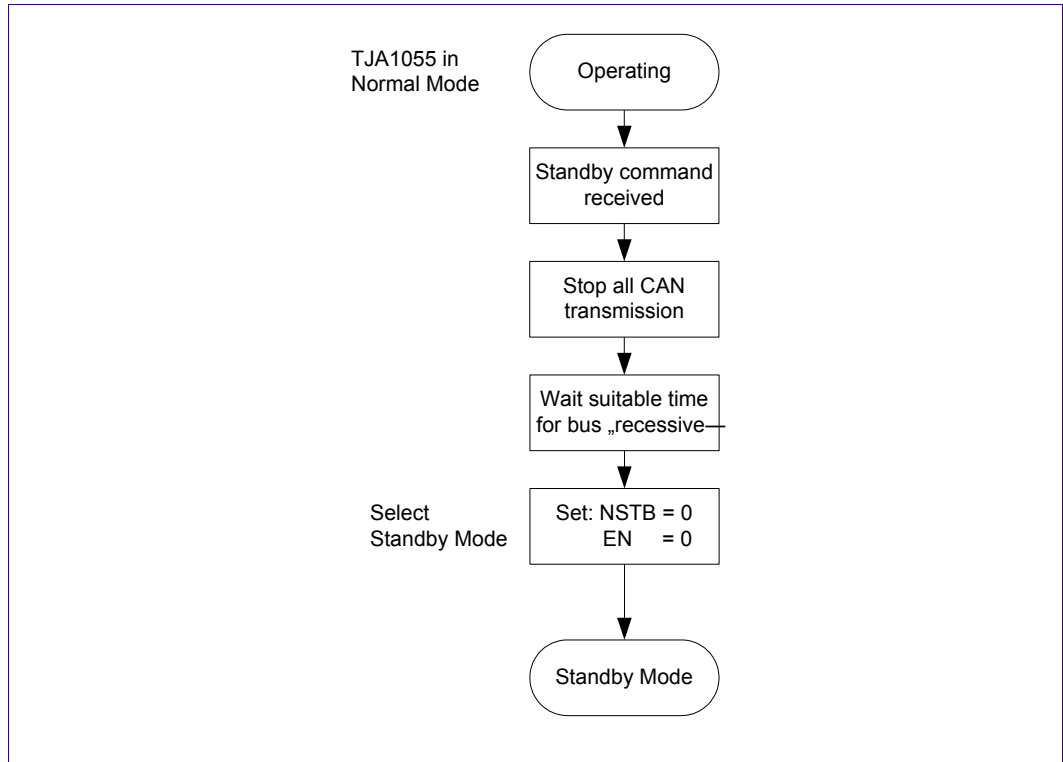
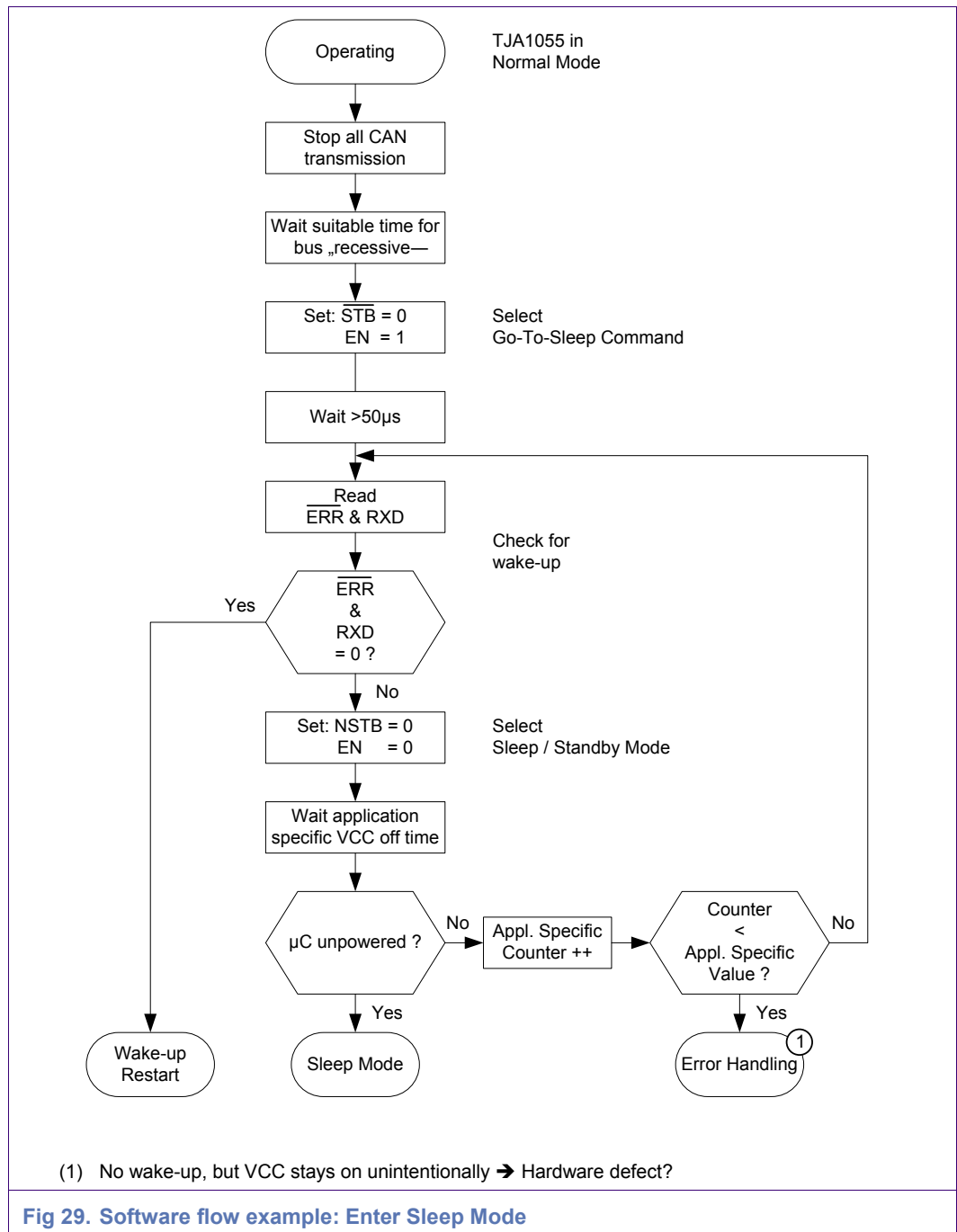


Fig 28. Software flow example: Enter Standby Mode

5.4.4 Example: How to enter Sleep Mode

The procedure to put an ECU into Sleep Mode is shown in Fig 29. For a safe Sleep Mode transition of a system it is recommended to take care on possible wake-up events, which might occur in the same moment. If the microcontroller drives the Go-To-Sleep command to the transceiver, the pin INH gets floating after the “reaction time of the Go-To-Sleep command” has been exceeded [2]. Followed to this change at INH, the application’s voltage regulator typically gets disabled, VCC ramps down and the host microcontroller gets unpowered. From system point of view it could happen, that the sleep process as described in Fig 29 gets interrupted by a wake-up event like a CAN message or an edge at the pin WAKE_N. As a result of this wake-up event, INH gets immediately HIGH again and VCC might keep stable all time due to the applied buffer capacitors. So the host microcontroller is continuously supplied without any power-on hardware reset even if it has performed the Go-To-Sleep procedure assuming that VCC will go down now.



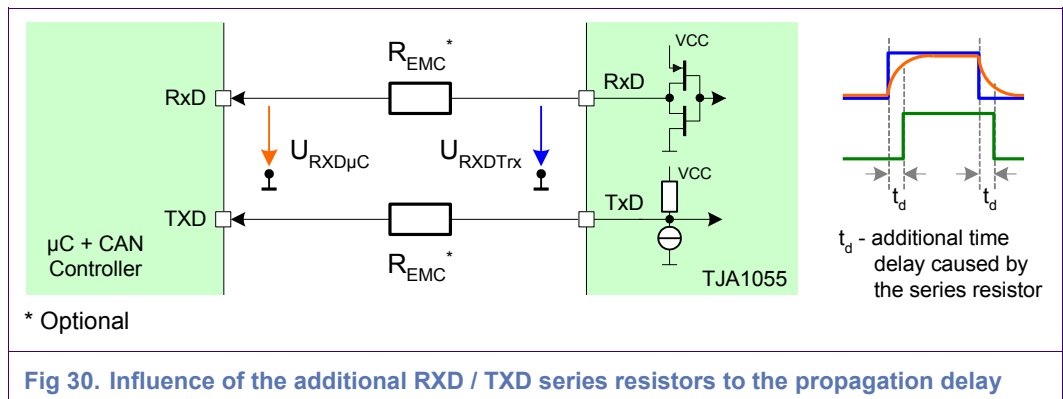
From software point of view, the application is recommended to check, whether the Go-To-Sleep procedure was successfully finished or not, monitoring the pins RXD or ERR_N. RXD and ERR_N are providing the wake-up information during Go-To-Sleep and Sleep coding on STB_N and EN. So if ERR_N or RXD signals a LOW during the Go-To-Sleep command, this is an indication that there was a wake-up event and VCC will keep active. Thus the software should react on this event as required by the application, e.g. restart the software (cold start).

6. EMC and ESD

6.1 EMI and EME improvements

6.1.1 Series resistors in TXD and RXD for EME improvement

The interface between μC and transceiver consists of two digital lines TXD and RXD, which are designed to provide sufficient drive capability for all application cases. This might increase the electromagnetic emission of the ECU when the applied signals show fast slops. Optionally it is possible to place a series resistor in the RXD and TXD lines to reduce this emission. This would help to smooth the edges during bit transmissions. But this will also increase the propagation delay, which has to be taken into account. Fig 30 shows the schematic of these optional resistors.



6.1.2 Common mode choke for improvements of RF-immunity

A common mode choke provides high impedance for common mode signals and low impedance for differential data signals. Due to this, common mode signals, either produced by RF noise or by the transceiver itself, get effectively attenuated while passing the choke. In fact, a common mode choke helps to reduce emission and to improve immunity against common mode disturbances. Whether a choke is needed or not depends on the system implementation and on the requirement of the car manufactures. When a common mode choke should be added then it has to be placed between the bus wires and the termination resistors R_{RTH} and R_{RTL} as shown Fig 31. But the choke shall also be placed nearest to the transceiver bus pins. In the following table there are listed the recommended common mode chokes for applications using the TJA1054T or TJA1055T.

Table 19 Recommended common mode chokes for the TJA1054T / TJA1055T

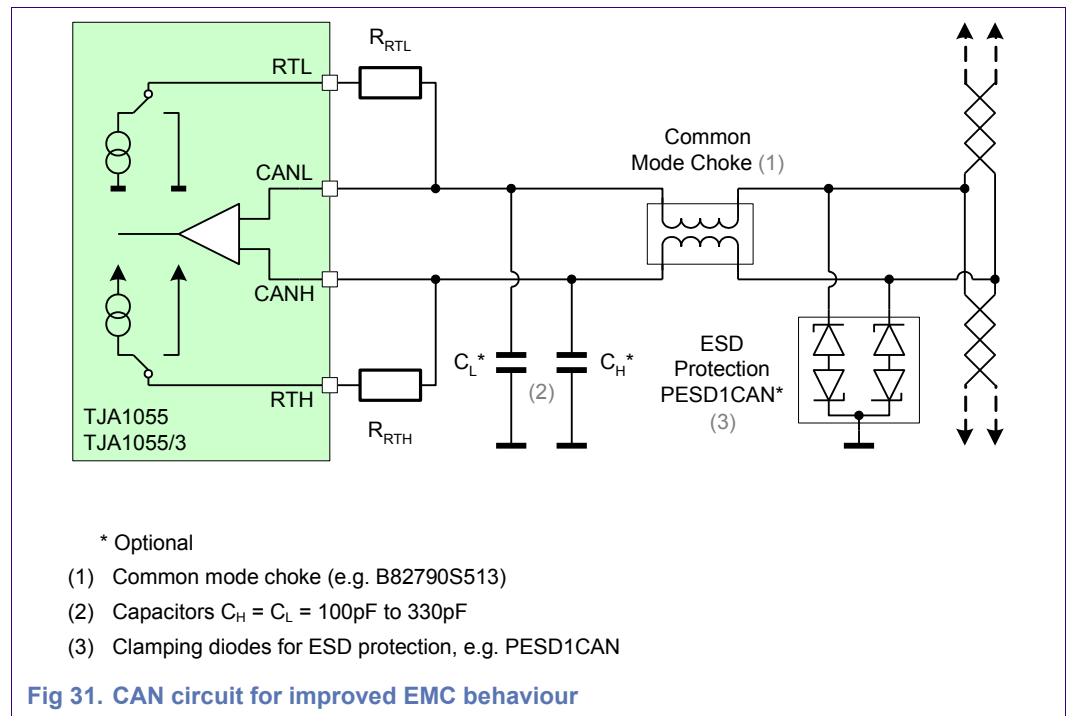
Choke typ	TJA1054T	TJA1055T
100 μH	YES ⁵	YES
51 μH	YES	YES

5 The stability of the TJA1054T ERR_N output signal at shorts between CANH to GND or CANL to VCC is affected by strong coupling between CANH and CANL.

The TJA1055T has the potential to build in-vehicle bus systems without chokes. Whether a choke is needed or not finally depends on the specific system implementation like the wiring harness and the symmetry of the two bus lines (matching tolerances of resistors and capacitors).

6.1.3 Bus capacitors for EMI improvements

Matching capacitors (in pairs) at CANH and CANL to GND (C_H and C_L) are frequently used to enhance immunity against electromagnetic interference. Along with the impedance of corresponding noise sources (RF), capacitors at CANH and CANL to GND are forming a RC low-pass filter. Regarding immunity the capacitor value should be as large as possible in order to achieve a low corner frequency. On the other hand, the overall capacitive load and the impedance of the output stage establish a RC low-pass filter for the data signals. Thus the associated corner frequency must be well above the data transmission frequency. This results in a limit for the capacitor value depending on the number of nodes and the data transmission frequency. Notice that capacitors are increasing the signal loop delay due to reducing rise and fall times. At a bit rate of 125kbit/s the capacitor value should not exceed 330pF. Typically, the capacitors are placed between the common mode choke (if applied at all) and the optional ESD clamping diodes as shown in Fig 31.



6.2 ESD protection with PESD1CAN

The TJA1055T is designed to withstand ElectroStatic Discharges (ESD) pulses up to 8kV according to the human body model and 6kV according to the IEC 61000-4-2 at the bus pins CANH, CANL and the termination pins RTL and RTH and thus typically does not need further external protection methods. However, if much higher protection is required, external clamping circuits can be applied to the optionally CANH and CANL line. In Fig 31 the optional external ESD protection is realized with the PESD1CAN at CANH and CANL to GND. The PESD1CAN is provided in small SOT23 SMD plastic package and designed to protect two CAN bus lines from the damage caused by ESD and other transients. The ESD protection diode PESD1CAN is especially designed to fulfill the demands of CAN bus lines. The PESD1CAN offers a very low diode capacitance of typical 11pF. It is recommended to apply the ESD protection circuitry close to the connectors of the ECU as shown in Fig 31.

7. Design Check List

Table 20 Check List for Hard- and Software Development

No	Item	Comment	Check √ / X
1	VCC	Check proper buffering according to 4.2.7.4.	
2	VCC	Bypass capacitors for the supply pin shall be connected as close as possible to the transceiver pin	
3	RTH RTL	Check for proper system termination, total termination has to be about 100 Ohms, a single node's termination is recommended not to exceed approx. 6k especially at long stubs.	
4	INH	INH is a VBAT related pin (open drain towards VBAT) and thus is NOT suitable to be connected directly to an input port of a microcontroller without external clamping or level adaptation. The continuous drive capability should be $\leq 1\text{mA}$.	
5	WAKE_N	WAKE_N is a VBAT related pin (internal pull-up to VBAT) and thus is NOT suitable to be connected directly to a microcontroller port without external clamping or level adaptation.	
6	WAKE_N	The output drive capability of the integrated pull-up to VBAT is intended to keep this pin on a defined level in case of an open circuit condition due to a failure on the PCB. This internal pull-up of some μA is NOT suitable to be driven directly by external circuitry like open collector bipolar transistors. The leakage current of such a transistor might be enough to cause a continuous LOW level at WAKE thus allowing no edges for wake-up anymore. An external default load or a push-pull driver is recommended here if this pin is used for local wake-up sources. (e.g. pull-up resistor to BAT ...)	
7	WAKE_N	An unused pin WAKE should not be left open due to immunity issues. Especially if some optional wiring is connected to this pin, this wire represents a potential antenna for environmental noise. Due to the integrated pull-up towards VBAT followed by an analogue filter, unwanted wake-up's are never observed for an open pin WAKE even with EMC load on it. Nevertheless it is recommended to connect an unused pin WAKE with the pin BAT of the transceiver for safety reasons. Pulling to VCC or GND permanently is NOT recommended because this would result in a continuous current flow out of the internal pull-up to BAT.	
8	WAKE_N	If the pin WAKE is directly connected to a wake-up source with separate GND connection (like an external switch to GND outside of the PCB) a series protection resistor is recommended as shown within the application diagram. This series resistor is used to limit the maximum current flowing in case the entire control unit has lost its GND connection. In this case, all the application current would flow through the external wake-up switch to GND. This may damage the transceiver. See also chapter 4.2.2.	

No	Item	Comment	Check
			√ / X
9	Choke	When a common mode choke is used, it shall be placed as close as possible to the transceiver bus pins CANH and CANL	
10	PCB	The PCB tracks for the bus signals CANH and CANL shall be routed close together in a symmetrical way. Its length should be as short as possible to the connector.	
11	PCB	CANL and CANH should be routed in parallel.	
12	PCB	Distance from microcontroller to the transceiver should be as short as possible.	
13	PCB	Distance from transceiver to the connector should be as short as possible.	
14	PCB	Connection of TXD, RXD, STB and EN to the host microcontroller should be in parallel to ground in order to guarantee a common reference level.	
15	PCB	Ground planes should be used whenever possible. For multilayer printed circuit boards, use ground vias.	
16	ESD	Optional suppressor diodes or varistors for ESD protection shall be connected close to the ECU connector bus terminal.	
17	PESD1CAN	Place the protection device as close as possible to the input terminal or connector of the ECU.	
18	Software	Check whether the Go-to-Sleep time $\geq t_{d(SLEEP)MAX}$	
19	Software	Check for late wake-up. It could happen that the Go-to-Sleep procedure is interrupted by a wake-up event (e.g. CAN message). As a result of this wake-up event the INH pin is set immediately high again and VCC might not keep stable all time due to applied buffer capacitors.	
20	Software	Check, whether EN pin is actively set low after exceeding the Go-to-Sleep time $\geq t_{d(SLEEP)MAX}$ with $VCC \geq 4V$ (see 5.1.4)	

8. FAQs

8.1 There was a wake-up event during the —Go to Sleep” procedure.

The pin WAKE is connected to the local 5V supply, which is controlled by the pin INH of the transceiver. In this case the Sleep Mode was entered successfully and the pin INH becomes floating. As a result of this the 5V supply is switched off -> VCC drops down. This forces an edge at WAKE_N and the device wakes up again. If WAKE_N is not used within the application it should be connected directly to the pin BAT of the transceiver (see also chapter 5.4.4).

There is an external CAN-Tool connected to the network and the GND connection between the PC and the application is missing. The floating bus wires are forcing wake-up events for the application.

The GND connection between separate powered nodes is lost. Result as discussed above.

8.2 System operates in Single Wire Mode all time

There is still a termination resistor between the bus wires present as known from the high-speed physical layer. E.g. a CAN tool with high-speed transceiver and termination is connected. The fault tolerant physical layer has **NO** termination resistor between the wires but a distributed termination at all nodes connected between pins CANH and RTH, CANL and RTL. See also chapter 9.1.

8.3 System does not wake-up, even if there is bus activity

For bus wake-up a CAN message with 5 consecutive dominant bits are required. This guarantees the minimum dominant time of 38us needed to wake-up the transceiver. Depending on the bit rate even messages with less than 5 consecutive dominant bits are sufficient to achieve the 38us dominant requirement.

Systems using the Standby Mode keeping the VCC supply alive are usually waked up with a dominant edge at RXD or ERR_N respectively. Depending on the uC hardware and software, this edge might be lost for the uC with the result that the uC enters its low-power mode (Stop Mode) with RXD and ERR_N continuously set LOW (wake-up). There are no further edges and thus the uC does not wake up. For these applications it is recommended to support a level sensitive wake-up or to make sure that all edges are recognized independently from software actions.

8.4 Transceiver is damaged when external tools are connected

Since PC's and other external equipment is typically supplied from the AC power supply while the car is isolated and supplied from a battery, there might be a very high voltage difference between both CAN networks. It is recommended to make sure that the GND

line between external stuff and the car is connected first, followed by the bus lines in order to have the same reference level.

8.5 CAN tool cannot communicate with certain application

Often a CAN tool is used to simulate the entire car environment for functional verifications of a single application. The problem is that the CAN tool does not provide the same termination resistance as present in the car's environment. In order to get this set-up running the CAN tool has to be supplied with a lower internal termination. It is recommended to replace the existing resistors inside of the CAN tool with e.g. 500 Ohms (the minimum allowed termination per transceiver) for test purposes. The total termination of all nodes should still keep above or equal to 100 Ohms.

9. Appendix

9.1 Bus Termination

9.1.1 Dimensioning of the bus termination resistors

The fault tolerant CAN transceiver TJA1055T is designed to deliver optimum system behavior at a total termination resistance of 100 Ohm at the line CANH as well as CANL. Because the termination of the fault tolerant system is distributed all over the network, each of the transceivers has to deliver only a part of the total termination of 100 Ohm. So depending on the overall system size the single nodes local termination resistors have to be adjusted to deliver optimum system performance.

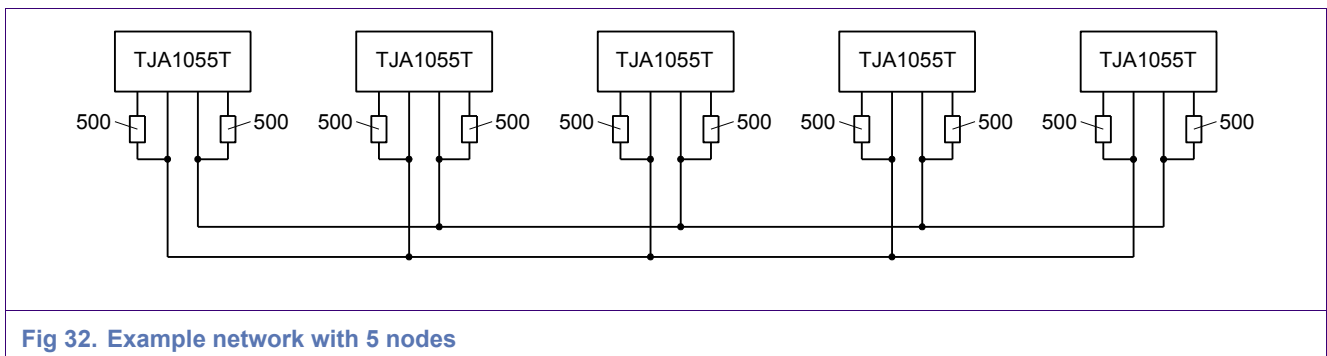


Fig 32. Example network with 5 nodes

The termination resistors are connected to the corresponding pins RTH and RTL of the transceivers within each control unit. It is not required that each transceiver in the system has the same termination resistor value. In total the termination should result in 100 Ohm per bus line. It is not recommended to terminate the entire system lower than 100 Ohm since the CAN output drivers are optimized for 100 Ohm load. A more low-ohmic termination might result in less GND shift capability during bus faults due to smaller signal amplitude.

The minimum termination resistor value allowed per transceiver is 500 Ohm due to the driving capability of the pins RTL and RTH. So within systems with less than 4 transceivers it is not possible to achieve the termination optimum of 100 Ohm. In practice this is typically no problem because such “small” systems will have less bus cable lengths compared to bigger networks and thus have no problem with a higher total termination resistances.

It is recommended not to exceed approximately a 6kOhm termination resistance at a single transceiver especially using long stubs in order to provide good system performance in case of interrupted bus wires.

9.1.1.1 Variable System Size and Optional Nodes

In case of variable system sizes with optional nodes it is recommended to achieve the total termination resistance close to 100Ohm provided by the standard nodes, which are always present. The optional nodes should have the higher termination resistances then. In order to keep tolerance against open wire conditions even for longer stub lines it is recommended not to exceed approximately 6kOhm for the optional nodes.

Example calculation

The entire example system has 15 nodes in total, 5 nodes of this system are equipped optionally if required:

- Termination of the 10 standard nodes: 1.2kOhm per node
- Termination of the 5 optional nodes: 3kOhm per node
- Total system termination (10 standard nodes only):
 - $1.2\text{ kOhm} / 10 = \underline{120\text{ Ohm}}$ (close to 100)
- Total system termination (10 standard nodes and 5 optional nodes):
 - $(3\text{ kOhm} / 5)\text{ parallel to }120\text{ Ohm} = \underline{100\text{ Ohm}}$

9.1.1.2 Distribution of the termination resistors

There is no general rule how to distribute the termination within the network, but a rule of thumb is:

–The longer the cable stub, the lower the local termination should be.”

It is recommended to keep the local time constant of a stub line below 1/6th of the bit time.

Table 21 Example values for termination resistor calculation

Symbol	Description	Value
L	Length of cable stub	5m
C'	Line capacitance	120pF/m
C _{ECU}	Capacitance of the ECU	100pF
t _{BIT}	Minimum bit duration (for 125kbit/s)	8μs

Capacitance: $C = L * C' + C_{ECU} = 5m * 120pF/m + 100pF = 700pF$

Local time constant: $1/6^{th} \tau = R * C$

$$R = \tau / (6 * C) = 8\mu s / 4200pF$$

$$R_t < 1900\text{ Ohm}$$

9.1.2 Tolerances of Bus Termination Resistors

The symmetry of the termination resistors within a single node has a major impact to the systems EME (Electro Magnetic Emission) behavior. Thus it is important to have well matched termination resistors within each control unit. This means that the RTH resistor should have exactly the same value as the RTL resistor within one control unit in order to get the same time constant on each bus wire during signal transitions. Two different control units might have completely different termination values (see chapter 9.1.1.1).

The principle to achieve a good EME performance is that the differential signal on the bus wires eliminates any emission due to compensation effects if both CAN wires are carrying exactly the same signal, but with inverse polarities.

Here the transceiver can only provide a perfect symmetry for the dominant transitions by design. The recessive transitions are mainly driven by the termination resistors and by the network cables. So not only the transceiver's output drivers have an impact to the EME performance but also the termination and the cable symmetry.

It is recommended to provide termination resistor accuracy (RTH compared to RTL) within the same node of maximum 1% or lower. Also the bus cable has to be at least a twisted pair cable in order to achieve a symmetrical capacitive load for both bus wires resulting in a good EMC performance.

It is obvious that also the layout of printed circuit boards has a significant impact to the EMC behavior if the CAN lines have different capacitive loads due to different wire lengths.

9.1.3 Power Dissipation of Termination Resistors

9.1.3.1 Summary

The bus termination resistors R_T being connected to the fault tolerant transceiver are recommended to withstand the power dissipation (@ $R_T \geq 1000$ Ohms) of **31,7mW**. The following chapters are discussing this issue in more detail.

9.1.3.2 Average power dissipation, no bus failures

In order to dimension the power dissipation of the termination resistors connected to pins RTH and RTL, the average power dissipation between dominant and recessive bits has to be taken into account. Additionally a worst-case ground offset of the certain module has an impact.

CAN frames are assumed to have a ratio of dominant bits in the range of 0.75 worst-case because of stuffing and fixed recessive frame segments. Thus the average power dissipation is calculated as follows:

$$P_{avg} = 0.75 * (V_{cc} + V_{GND})^2 / R_T$$

Hint: For this calculation it is assumed that RTL is pulled to VCC while this ECU has 1,5V GND shift compared to the rest of the system and the bus driver of the sending node is able to pull CANL towards the real system GND without any drop (super worst case).

Example calculation, average power dissipation

Assumption: $R_T = 1000$ Ohm

$$P_{avg} = 0.75 * (5V + 1,5V)^2 / 1000 \text{ Ohm} = \mathbf{31.7 \text{ mW}}$$

9.1.3.3 Maximum continuous power dissipation (single bus failure)

The maximum continuous current flows in case CANH has a short to V_{CC} or BAT at the maximum detection threshold of 1.85V.

$$P_{cont} = (V_{det \ max})^2 / R_T$$

Hint: If CANH would be pulled to a higher voltage, the bus failure management would disable RTH and thus interrupt the RTH current.

Example calculation, maximum continuous power dissipation

Assumption: $R_T = 1000$ Ohm, connected to RTH

$$P_{cont} = (1.85 \text{ V})^2 / 1000 \text{ Ohms} = \mathbf{3.4 \text{ mW}}$$

9.1.3.4 Maximum peak power dissipation (single bus failure)

A peak current will flow in case of short circuits of CANH to VBAT. After the device maximum specific detection time of 8ms, the bus failure detector will switch off the bias on RTH. Thus this peak current does only flow for a short time.

$$P_{peak} = V_{BAT}^2 / R_T \ (t < t_{det_HBAT})$$

Example calculation, maximum peak power dissipation

Assumptions: $R_T = 1000$ Ohms, $V_{BAT} = 27V$

$$P_{peak} = (27 \text{ V})^2 / 1000 \text{ Ohms} = \mathbf{730 \text{ mW}} \text{ for less than } \mathbf{8 \text{ ms}}$$

Because this peak current does flow for a very short time only, it typically has no relevance for dimensioning the termination resistors. Most important is the average power dissipation for the TJA1055T (31,7 mW) since this is the worst-case condition.

9.2 Bus Failure Management

This chapter gives an overview and description of the failure mechanisms in a fault tolerant CAN network. It describes the error detection, the error signaling, the error recovery and the transceiver behaviour during bus fault conditions. Latter means the CAN driver and termination activation and deactivation.

9.2.1 Overview of transceiver state in Normal Mode

The failure detector is fully active in the normal operating mode. After the detection of a single bus failure the detector switches to the appropriate mode. The differential receiver threshold voltage is set at -3.2 V typical ($V_{CC} = 5\text{ V}$). This ensures correct reception with a noise margin as high as possible in the normal operating mode and in the event of failures 1, 2, 5 and 6a. These failures, or recovery from them, do not destroy ongoing transmissions. The output drivers remain active, the termination does not change and the receiver remains in differential mode (see Table 22).

Table 22 Bus failures and driver output states in Normal Mode)

Failure No.	Description	Termination		Driver		Receiver Mode
		CANH (RTH) ⁶	CANL (RTL) ⁷	CANH	CANL	
0	No failure	On	On	On	On	Differential
1	CANH wire interrupted	On	On	On	On	Differential
2	CANL wire interrupted	On	On	On	On	Differential
3	CANH short to BAT	weak	On	Off	On	CANL
3a	CANH short to VCC	weak	On	Off	On	CANL
4	CANL short to GND	On	weak	On	Off	CANH
5	CANH short to GND	On	On	On	On	Differential
6	CANL short to BAT	On	weak	On	Off	CANH
6a	CANL short to VCC	On	On	On	On	Differential
7	CANL short to CANH	On	weak	On	Off	CANH

⁶ A weak termination implies a pull-down current source behavior of 75 μA typical.

⁷ A weak termination implies a pull-up current source behavior of 75 μA typical.

9.2.2 Failure overview and description

Table 23 Failure 1 – CANH wire interrupted

Error description		<p>This failure is only detectable in normal operating mode during bus activity. The communication between node A, B and C is not affected at all. Depending on the sender, the ERR_N pin at the various nodes might toggle.</p> <p>The open wire is detected and signalled only for receiving nodes, if the interruption is located on the path towards the sending node.</p>
Error detection	<p>All dominant edges on the bus are counted and compared between the differential receiver and the single ended receivers on CANH and CANL. Each missing edge increases the counter by one. If the difference of the pulse-counter is equal or higher than 4 a failure is signalled on pin ERR_N.</p>	
Receiver	<p>The receiver remains in differential mode. No received data lost.</p>	
Driver	<p>The drivers of CANH and CANL remain enabled.</p>	
Error recovery	<p>This error is recovered after the detection of 4 consecutive dominant pulses on both bus lines. The ERR_N pin goes HIGH again.</p>	

Table 24 Failure 2 – CANL wire interrupted

Error description		<p>This failure is only detectable in normal operating mode during bus activity. The communication between node A, B and C is not affected at all. Depending on the sender, the ERR_N pin at the various nodes might toggle.</p> <p>The open wire is detected and signalled only for receiving nodes, if the interruption is located on the path towards the sending node.</p>
Error detection	<p>All dominant edges on the bus are counted and compared between the differential receiver and the single ended receivers on CANH and CANL. Each missing edge increases the counter by one. If the difference of the pulse-counter is equal or higher than 4 a failure is signalled on pin ERR_N.</p>	
Receiver	<p>The receiver remains in differential mode. No received data lost.</p>	
Driver	<p>The drivers of CANH and CANL remain enabled.</p>	
Error recovery	<p>This error is recovered after the detection of 4 consecutive dominant pulses on both bus lines. The ERR_N pin goes HIGH again.</p>	

Table 25 Failure 3 – CANH short-circuited to battery

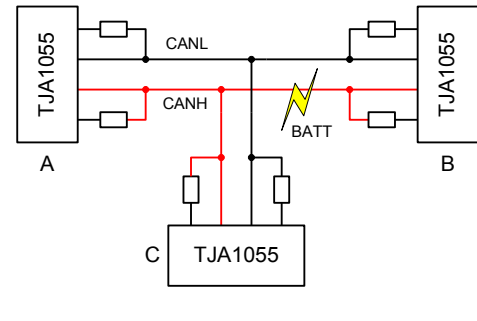
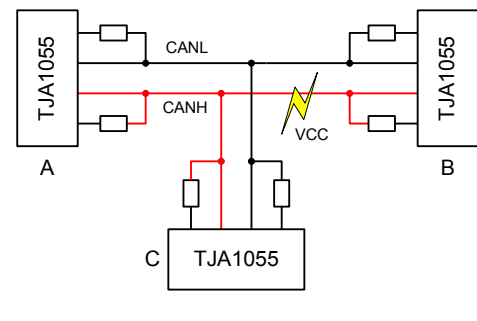
<p>Error description</p>		<p>This failure is detectable in all operating modes. The CANH line is clamped to VBAT level preventing all communication on that line in the whole network. The transceiver switches to single-wire communication on CANL. Pin ERR_N signals an error as a continuous LOW signal.</p>
<p>Error detection</p>	<p>Failure 3 is detected via comparators connected to the CANH and the differential bus comparator. The CANH to BAT short is detected in a two-step approach. If the CANH bus line exceeds a certain voltage level, the differential comparator signals a continuous dominant condition. After a first time-out the transceiver switches to single-wire operation through CANH. If the CANH bus line still exceeds the CANH dominant voltage for a second time-out, the TJA1055T switches to CANL operation; the CANH driver is switched off and the RTH bias changes to the pull-down current source.</p>	
<p>Receiver</p>	<p>The receiver switches to CANL. The failure detection might cause a CAN error frame.</p>	
<p>Driver</p>	<p>The driver of CANH is disabled.</p>	
<p>Error recovery</p>	<p>This error is recovered if the differential and single wire comparators show a recessive level for a certain time. The ERR_N pin goes HIGH again.</p>	

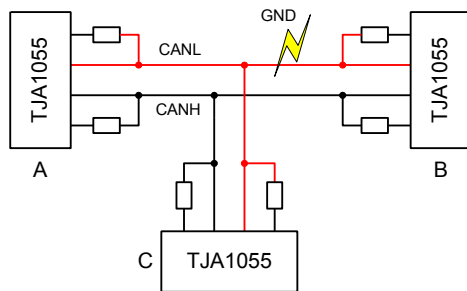
Table 26 Failure 3a – CANH short-circuited to VCC

<p>Error description</p>		<p>This failure is detectable in all operating modes. The CANH line is clamped to VCC level preventing all communication on that line in the whole network. The transceiver switches to single-wire communication on CANL. Pin NERR signals an error as a continuous LOW signal.</p>
<p>Error detection</p>	<p>Failure 3a is detected via comparators connected to the CANH and the differential bus comparator. The CANH to VCC short is detected in a two-step approach. If the CANH bus line exceeds a certain voltage level, the differential comparator signals a continuous dominant condition. After a first time-out the transceiver switches to single-wire operation through CANH. If the CANH bus line still exceeds the CANH dominant voltage for a second time-out, the TJA1055T switches to CANL operation; the CANH driver is switched off and the RTH bias changes to the pull-down current source.</p>	
<p>Receiver</p>	<p>The receiver switches to CANL. The failure detection might cause a CAN error frame.</p>	
<p>Driver</p>	<p>The driver of CANH is disabled.</p>	

Error recovery . This error is recovered if the differential and single wire comparators show a recessive level for a certain time. The ERR_N pin goes HIGH again.

Table 27 Failure 4 – CANL short-circuited to GND

Error description



This failure is detectable in all operating modes. The CANL line is clamped to GND level preventing all communication on that line in the whole network.

For CANL the GND level is the dominant state. Communication is only possible on CANH. The nodes A, B and C switch into single wire mode. Pin ERR_N signals the error as a continuous LOW signal.

Error detection Failure 4 results in a permanent dominant level on the differential comparator. After a time-out the CANL driver is switched off and the RTL bias changes to the pull-up current source. Reception continues by switching to the single-wire mode via pin CANH.

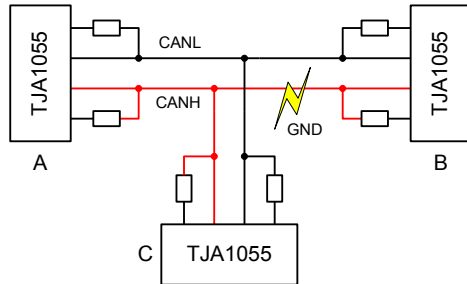
Receiver The receiver switches to CANH. The failure detection might cause a CAN error frame.

Driver The driver of CANL is disabled.

Error recovery This error is recovered if the differential voltage remains below the recessive threshold level for a certain period of time; reception and transmission switch back to the differential mode. The ERR_N pin goes HIGH again.

Table 28 Failure 5 – CANH short-circuited to GND

Error description



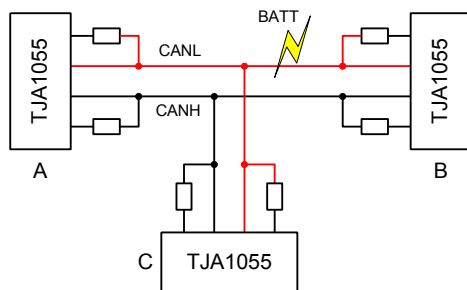
This failure is detectable only during communication in normal mode. CANH line is clamped to GND level preventing all communication on that line in the whole network.

GND is the recessive state of CANH. If the transceiver receives a dominant bit via the differential comparator but not on CANH the internal error counter is increased by one. The communication between node A, B and C is not affected at all. Pin NERR signals the error as a continuous LOW signal.

Error detection	All dominant edges on the bus are counted and compared between the differential signal, CANH and CANL. Each missing edge increases the counter. If the difference of the pulse-counter is equal or higher than 4 a failure is signaled on pin ERR_N.
Receiver	The receiver stays in differential mode; no ongoing transmission is lost.
Driver	The output driver remains active.
Error recovery	This error is recovered after the detection of 4 consecutive dominant pulses on both bus lines. The ERR_N pin goes HIGH again.

Table 29 Failure 6 – CANL short-circuited to battery

Error description



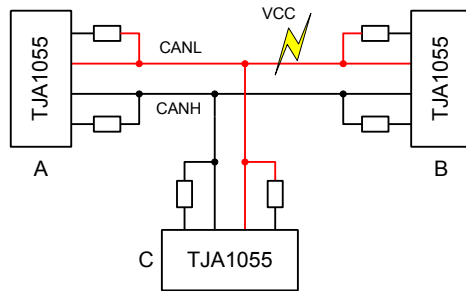
This failure is detectable in normal mode. The CANL line is clamped to VBAT level preventing all communication on that line in the whole network. The transceiver switches into single-wire communication on CANH.

Pin ERR_N signals an error as a continuous LOW signal.

Error detection	Failure 6 is detected via comparator connected to CANL bus line. If the CANL bus line exceeds a certain voltage level close to the battery voltage for a certain period of time the transceiver switches to single-wire operation through CANH.
Receiver	The receiver switches to CANH. The failure detection might cause a CAN error frame.
Driver	The CANL driver switches off.
Error recovery	This error is recovered automatically as soon as the voltage threshold of the CANL comparator falls below the detection level for a defined time. The ERR_N pin goes HIGH again.

Table 30 Failure 6a – CANL short-circuited to VCC

Error description



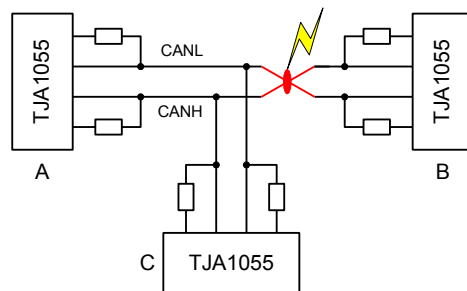
This failure is detectable only during communication in normal mode. VCC is the recessive state of CANL. CANL line is clamped to VCC level preventing all communication on that line in the whole network.

Communication is only possible on CANH. The nodes A, B and C switches to single wire mode. Pin ERR_N signals an error flag as a continuous LOW signal.

Error detection	Failure 6 is detected via comparators connected to the CANH and CANL bus lines and the differential comparator. All dominant edges on the bus are counted and compared between the differential signal, CANH and CANL. Each missing edge increases the counter. If the difference of the pulse-counter is equal or higher than 4 a failure is signaled on pin ERR_N.
Receiver	The receiver remains in differential mode. No received data lost.
Driver	The drivers of CANH and CANL remain enabled.
Error recovery	This error is recovered after the detection of 4 consecutive dominant pulses on both bus lines. The ERR_N pin goes HIGH again.

Table 31 Failure 7 – CANL and CANH mutually short-circuited

Error description



The two CAN lines are mutually short-circuited and carry the messages with the same voltage level. This voltage is lower than in normal differential communication.

This failure is detected in all modes and result in a switch to single wire mode. The communication will take place on CANH. Pin ERR_N signals an error flag as a continuous LOW signal.

Error detection	Failure 7 results in a permanent dominant level at the differential comparator. After a certain time-out the CANL driver is switched off and the RTL bias changes to the pull-up current source. Reception continues by switching to the single-wire mode via pins CANH.
Receiver	The receiver switches to CANH. The failure detection might cause a CAN error frame.
Driver	The driver of CANL is disabled.
Error recovery	This error is recovered if the differential voltage remains below the recessive threshold level for a certain period of time; reception and transmission switch back to the differential mode. The ERR_N pin goes HIGH again.

9.3 Pin FMEA

This chapter provides a FMEA (Failure Mode and Effect Analysis) for the typical failure situations, when dedicated pins of the TJA1055T are short-circuited to supply voltages like V_{BAT} , V_{CC} , GND or to neighbored pins or are simply left open. The individual failures are classified, due to their corresponding effects on the transceiver and bus communication.

Table 32 Classification of failure effects

Class	Effects
A	<ul style="list-style-type: none">- Damage to transceiver- Bus may be effected
B	<ul style="list-style-type: none">- No damage to transceiver- No bus communication possible
C	<ul style="list-style-type: none">- No damage to transceiver- Bus communication possible- Corrupted node excluded from communication
D	<ul style="list-style-type: none">- No damage to transceiver- Bus communication possible- Reduced functionality of transceiver

Table 33 FMEA matrix for pin short-circuits to V_{BAT}

Short to VBAT (12V...40V)		
Pin	Class	Remark
(1) INH	D	The external voltage regulator keeps on permanently and avoids saving current in Low Power.
(2) TXD	A	Limiting value exceeded. This might result in the damage of the TJA1055T transceiver the connected TXD output of the microcontroller.
(3) RXD	A	Limiting value exceeded. This might result in the damage of the TJA1055T transceiver the connected RXD input of the microcontroller.
(4) ERR_N	A	Limiting value exceeded. This might result in the damage of the TJA1055T transceiver the connected ERR_N input of the microcontroller.
(5) STB_N	A	Limiting value exceeded. This might result in the damage of the TJA1055T transceiver the connected STB_N output of the microcontroller.
(6) EN	A	Limiting value exceeded. This might result in the damage of the TJA1055T transceiver the connected EN output of the microcontroller.
(7) WAKE_N	D	No local wake-up via WAKE_N is possible.
(8) RTH	D	The short-circuit current is limited by the RTH driver. Depending on the total bus system size and the termination balancing the bus communication might switch to single-wire mode. In big bus systems the impact will be low due to local termination resistances.
(9) RTL	D	The short-circuit current is limited by the RTL driver. Depending on the total bus system size and the termination balancing the bus communication might switch to single-wire mode. In big bus systems the impact will be low due to local termination resistances.
(10) V _{CC}	A	A V _{CC} to BAT shortcut results in the damage of the TJA1055T transceiver and all other components connected to the V _{CC} supply like the microcontroller.
(11) CANH	D	The bus failure management of the transceiver detects a CANH short to BAT, signals this via a LOW level on pin ERR_N and switches to single-wire communication mode. The bus communication is not further negatively influenced.
(12) CANL	D	The bus failure management of the transceiver detects a CANL short to BAT, signals this via a LOW level on pin ERR_N and switches to single-wire communication mode. The bus communication is not further negatively influenced.
(13) GND	C	The short does not have a direct impact on the transceiver. An under voltage condition (power-on reset) will be detected and the Standby Mode be entered. If the recommended series resistor of 1...2k is implemented within the BAT line the current flow will be limited.
(14) BAT	-	Not applicable

Table 34 FMEA matrix for pin short-circuits to V_{CC}

Short to V _{CC} (5V)		
Pin	Class	Remark
(1) INH	D	With a voltage regulator connected to pin INH, this one might stay active forever, depending on its input threshold. If no voltage regulator is connected to the INH pin, the INH to V _{CC} current is limited internally of the TJA1055T.
(2) TXD	C	The transmission of messages is not possible anymore. The reception of messages is not affected.
(3) RXD	B	The CAN controller will see a permanently „free-bus and might as a result launch messages with random timing. This can lead to a globally corrupted CAN bus communication. The used software can prevent such a system wide problem by monitoring back the CAN controller's behaviour.
(4) ERR_N	D	A bus failure diagnosis is not possible.
(5) STB_N	D	No Sleep Mode possible. The system can switch between Normal, Standby and Power-on Standby only
(6) EN	D	The Power-on Standby Mode is not available.
(7) WAKE_N	D	Internally of the TJA1055T the weak current source from WAKE_N to BAT is protecting itself by a current limitation. If the V _{CC} supply gets disabled in Sleep Mode this might cause a wake-up starting the V _{CC} supply again.
(8) RTH	D	The short-circuit current is limited by the RTH driver. Depending on the total bus system size and the termination balancing the bus communication might switch to single-wire mode. In big bus systems the impact will be significantly low due to local termination resistances.
(9) RTL	D	V _{CC} is the nominal driver value for the RTL pin. Consequently the bus failure management gets not affected.
(10) V _{CC}	-	Not applicable
(11) CANH	D	The bus failure management of the transceiver detects a CANH short to V _{CC} , signals this via a LOW level on pin ERR_N and switches to single-wire communication mode. The bus communication is not further negatively influenced.
(12) CANL	D	The bus failure management of the transceiver detects a CANL short to V _{CC} , signals this via a LOW level on pin ERR_N and switches to single-wire communication mode. The bus communication is not further negatively influenced.
(13) GND	C	The short does not have a direct impact on the transceiver. The external voltage regulator might become overloaded and be switched off. Hence the transceiver detects a low V _{CC} supply and gets into a „Forced Standby Mode”, similar to switching STB_N and EN to LOW. CAN communication is not longer possible. The problem only affects the local ECU.
(14) BAT	A	A BAT to V _{CC} shortcut results in the damage of the TJA1055T transceiver and all other components connected to the V _{CC} supply like the microcontroller.

Table 35 FMEA matrix for pin short-circuits to GND

Short to GND		
Pin	Class	Remark
(1) INH	C	With a voltage regulator connected to pin INH, this one will stay off permanently. If no voltage regulator is connected to the INH pin, the INH to GND current is limited internally of the TJA1055T.
(2) TXD	C	The TXD dominant timer makes sure that the bus is not clamped dominant forever. As a result the failure stays local, since no transmission of messages from this node is possible. The reception of messages is not affected.
(3) RXD	C	The CAN controller will see a permanently "clerked" bus and thus never start with CAN communication. The problem only affects the local ECU.
(4) ERR_N	D	The software assumes a bus failure condition and tracks this within a possible diagnosis system.
(5) STB_N	C	The "Go to Sleep" command will be forced to the transceiver, if the microcontroller's port HIGH level is weaker than the STB_N pin's LOW driver (high probability) and the EN pin is set HIGH. As a result the transceiver will enter the Low Power Mode and disable the application.
(6) EN	C	The system is permanently in Standby Mode. No communication is possible. The transceiver requires only low current.
(7) WAKE_N	D	Internally of the TJA1055T the weak current source from WAKE_N to BAT is protecting itself by a current limitation. As a result of the shortcut no wake-up via WAKE_N is possible.
(8) RTH	D	GND is the nominal driver value for the RTH pin. Consequently the bus failure management gets not affected.
(9) RTL	D	The short-circuit current is limited by the RTL driver. Depending on the total bus system size and the termination balancing the bus communication might switch to single-wire mode. In big bus systems the impact will be low due to local termination resistances.
(10) V _{CC}	C	The short does not have a direct impact on the transceiver. The external voltage regulator might become overloaded and be switched off. Hence the transceiver detects a low V _{CC} supply and gets into a "Forced Standby Mode", similar to switching STB_N and EN to LOW. CAN communication is not longer possible. The problem only affects the local ECU.
(11) CANH	D	The bus failure management of the transceiver detects a CANH short to GND, signals this via a LOW level on pin ERR_N and switches to single-wire communication mode. The bus communication is not further negatively influenced.
(12) CANL	D	The bus failure management of the transceiver detects a CANL short to GND, signals this via a LOW level on pin ERR_N and switches to single-wire communication mode. The bus communication is not further negatively influenced.
(13) GND	-	Not applicable
(14) BAT	C	The short does not have a direct impact on the transceiver. An under voltage condition (power-on reset) will be detected and the Standby Mode be entered. If the recommended series resistor of 1...2k is implemented within the BAT line the current flow will be limited.

Table 36 FMEA matrix for open pins

Pin	Open	
	Class	Remark
(1) INH	C	With a voltage regulator connected to pin INH, this one will not start and the ECU will stay in Low Power Mode. If no voltage regulator is connected to the INH pin, no problem occurs.
(2) TXD	C	The transmission of messages is not possible anymore. The reception of messages is not affected.
(3) RXD	C	The CAN controller gets no feedback from the bus while transmitting and runs BUS-OFF within a short time. The problem only affects the local ECU once bus off is achieved.
(4) ERR_N	D	A bus failure diagnosis is not possible.
(5) STB_N	C	The internal pull-down source of the transceiver makes sure that the STB_N pin internally is LOW. The "Go to Sleep" command will be forced to the transceiver, if the EN pin is set HIGH. As a result the transceiver will enter the Low Power Mode and disable the application.
(6) EN	C	The internal pull-down source of the transceiver makes sure that the EN pin internally is LOW. Consequently the system is permanently in Standby Mode. No communication is possible. The transceiver requires only low current.
(7) WAKE_N	D	Internally of the TJA1055T the weak current source from WAKE_N to BAT makes sure that no undefined input conditions occur. No local wake-up via WAKE_N is possible.
(8) RTH	D	The open RTH pin causes a slightly weaker single ended termination resistance. This has a slight impact to the signal symmetry on the CAN bus and causes slightly higher emission values. In big bus systems the impact will be low due to local termination resistances.
(9) RTL	D	The open RTL pin causes a slightly weaker single ended termination resistance. This has a slight impact to the signal symmetry on the CAN bus and causes slightly higher emission values. In big bus systems the impact will be y low due to local termination resistances.
(10) V _{CC}	C	The transceiver detects a low V _{CC} supply and gets into a "Forced Standby Mode", similar to switching STB_N and EN to LOW. CAN communication is not longer possible. The problem only affects the local ECU.
(11) CANH	D	The bus failure management of the transceiver detects a CANH open wire condition and signals this via a LOW level on pin ERR_N. The bus communication is not further negatively influenced.
(12) CANL	D	The bus failure management of the transceiver detects a CANL open wire condition and signals this via a LOW level on pin ERR_N. The bus communication is not further negatively influenced.
(13) GND	C	The design of the TJA1055T avoids loading the remaining bus system, if there is a loss of power situation. Consequently the problem only affects the local ECU.
(14) BAT	C	The design of the TJA1055T avoids loading the remaining bus system, if there is a loss of power situation. Consequently the problem only affects the local ECU.

Table 37 FMEA matrix for pin short-circuits between neighbored pins

Short to neighbored pin		
Pin	Class	Remark
INH-TXD	C	The INH pin offers a weak source to BAT. The TXD driver of the microcontroller will overrule this signal. With a voltage regulator connected to pin INH, this one might be switched off with dominant TXD input signal from the microcontroller and shut down the V _{CC} supply. This leads to an ECU reset. If no voltage regulator is connected to the INH pin, the INH to TXD current is limited internally of the TJA1055T.
TXD-RXD	B	The RXD pin includes a push-pull driver that will most likely overrule the TXD output of the microcontroller. This can lead to a temporary lock situation, since a dominant bus level is forwarded from the RXD pin back via the TXD pin to the bus. The TXD dominant timer makes sure that the bus is not clamped dominant forever. This deadlock recovers automatically, if the short is removed. Consequence: The bus is globally blocked until the RXD to TXD short is removed.
RXD-ERR_N	C	The ERR_N pin provides a weak pull-up that will be overruled by the RXD signal, if no bus failure is present. With a bus failure condition (ERR_N = LOW) the CAN controller assumes a busy CAN bus and stops to emit CAN messages. The problem only affects the local ECU.
ERR_N-STB_N	C	A bus failure condition (ERR_N = LOW) will force the “Go to Sleep” command to the transceiver, if the microcontroller’s port HIGH level is weaker than the ERR_N pin’s LOW driver (high probability). As a result the transceiver will enter the Low Power Mode and disable the application.
STB_N-EN	D	Depending on the port structure of the connected microcontroller (driver strength) the system can change between Normal Mode and Standby Mode only.
EN-WAKE_N	D	The WAKE_N pin provides a weak pull-up to BAT. This pull-up is typically overruled by microcontroller signal connected to the pin EN. At a system change to a Low Power Mode a wake-up is received via the shorted WAKE_N port. Consequently the system cannot enter its Low Power Mode.
RTH-RTL	D	Depending on the total bus system size and the termination balancing the bus communication might switch to single-wire mode. In big bus systems the impact will be low due to local termination resistances.
RTL-V _{CC}	D	V _{CC} is the nominal driver value for the RTL pin. Consequently the bus failure management gets not affected.
V _{CC} -CANH	D	The bus failure management of the transceiver detects a CANH short to V _{CC} , signals this via a LOW level on pin ERR_N and switches to single-wire communication mode. The bus communication is not further negatively influenced.
CANH-CANL	D	The bus failure management of the transceiver detects a CANH short to CANL, signals this via a LOW level on pin ERR_N and switches to single-wire communication mode. The bus communication is not further negatively influenced.
CANL-GND	D	The bus failure management of the transceiver detects a CANL short to GND, signals this via a LOW level on pin ERR_N and switches to single-wire communication mode. The bus communication is not further negatively influenced.
GND-BAT	C	The short does not have a direct impact on the transceiver. An under voltage condition (power-on reset) will be detected and the Standby Mode be entered. If the recommended series resistor of 1...2k is implemented within the BAT line the current flow will be limited.

9.4 Ground Shift

9.4.1 GND shift definitions

The fault-tolerant transceivers are designed to detect bus failure situation using different types of comparators, monitoring the bus lines in order to detect failure situations. Upon detected failures, the transceiver changes the mode of operation in order to keep the communication running.

With respect to GND shift and EMC issues, the differential mode of operation is preferred. Thus, whenever possible, this mode of operation is used, offering a maximum GND shift capability in the system. In case differential operation is not possible anymore, the transceiver switches to single wire operation making use of single-ended receive comparators. These comparators are comparing the single-ended bus signal with respect to GND. This is, why the single-wire operation mode in general cannot offer the same GND shift capability as like possible within differential operating mode.

Compared to the battery GND signal, a node can be shifted in positive direction only. Nevertheless from system point of view, a node can virtually have a negative GND shift taking the CAN bus signals as a reference.

Positive GND shifts

This is the most common case dealing with a poor GND connection of a single ECU. In this case, all nodes with good GND connection dominate the bus signal while the ECU with GND problem is shifted in positive direction. Here the ECU with poor GND connection observes a shift of the bus signals in negative direction. Compared to its local (poor) GND, the recessive CANH wire seems to be below 0V while CANL does not reach its 5V recessive level anymore.

Negative GND shifts

This is the more unusual case, which can be achieved only, if all nodes in the system have a poor GND connection while there is one ECU with a proper GND connection. In this strange situation the ECU with proper GND connection observes a shift of the bus signals in positive direction due to the dominating system with poor GND. The CANH wire never reaches the 0V recessive level, while the recessive CANL wire climbs above the 5V level.

9.4.2 GND shift limitations

No bus failure present

When there is no bus failure present, the differential communication takes place, making use of the differential receiver. Here a relative wide range of GND shift is possible.

Positive GND shift

For the most common positive GND shifts, there is no fundamental limit coming from the bus failure management itself. Here the physical parameters of the networking itself are limiting the GND shift capabilities. If a node is shifted in positive direction, the timing of the bits is the most critical parameter. Thus depending on the bit rate, the cable lengths and the termination scenario the GND shift capabilities are changing. Within a real system with 25 nodes, 55m of bus cable, multi star topology and 100kBit/s, up to +5V GND shift are tolerated by the system using the TJA1054T or TJA1055T transceiver. This is proven within a real hardware set-up.

Negative GND shift

In the more unlikely event of negative GND shifts (the entire network has a poor GND except of one node) the bus failure management becomes active at about -1.6V GND shift. Here the single ended CANH receiver of the node with negative GND shift becomes continuously dominant due to the GND shift. Thus this transceiver switches over to single wire mode using CANL. Nevertheless the communication is still ok. At -2.1V GND shift the communication is down, because here even the CANL receiver cannot see a bus signal anymore. CANL carries now $5V + 2.1V = 7.1V$ (recessive) and about 3.5V (dominant). Thus the threshold of the receiver is not passed and there is no communication possible anymore.

9.4.3 CANH interruption

Positive GND shift

Here the differential receiver limits the communication. Since CANH is interrupted, this wire stays at about 0V during reception of messages from the system, while CANL offers the bit stream. Due to the positive shift, CANL does not reach the +5V recessive level anymore. Thus, starting from a certain positive GND shift level, the differential receiver gets continuously dominant and no reception is possible anymore. Within the previously mentioned system (see chapter 9.4.1) up to +2.1V are reached.

Negative GND shift

With negative GND shifts, again the differential comparator threshold defines the limit. Since again CANH stays locally at 0V, while the CANL dominant level is getting more and more positive, the differential comparator becomes continuously recessive. Thus, no reception of messages is possible anymore. Within the previously mentioned system (see chapter 9.4.1) up to -2.1V are reached.

9.4.4 CANL interruption

Positive GND shift

Again the differential comparator limits the communication capabilities. With positive GND shifts, the differential comparator becomes continuously recessive, because CANH becomes more and more negative for the affected node. Within the previously mentioned system (see chapter 3.1.1) up to +2.0V are reached.

Negative GND shift

Here the limitation is caused by the same effect explained within chapter 9.4.1. At about -1.6V, the CANH comparator becomes continuously dominant, thus switching to the interrupted CANL wire.

9.4.5 CANH shorted to BAT or VCC

Positive GND shift

Here the communication via CANL takes place since CANH is recognised to be dominant continuously. With positive GND shift, the CANL signal will become continuously dominant and thus shutdown any communication. Within the previously mentioned system (see chapter 9.4.1) up to +1.6V are reached.

Negative GND shift

Again the communication via CANL takes place since CANH is recognised to be dominant continuously. With negative GND shift, the CANL signal will become continuously recessive and thus shutdown any communication. Within the previously mentioned system (see chapter 9.4.1) up to -2.1V are reached.

9.4.6 CANH shorted to GND

Positive GND shift

With CANH shorted to a recessive voltage (GND), the transceivers still operate in differential mode. Now the limitation is reached, if the device with GND shift sends towards the system without GND shift. All nodes, trying to receive this message will see a continuous recessive bus, because the node with positive shift cannot pull CANL low enough to pass the differential threshold voltage. Within the previously mentioned system (see chapter 9.4.1) up to $+2.0\text{V}$ are reached.

Negative GND shift

Here the same mechanism as explained within chapter 9.4.1 takes place. Starting from a certain negative voltage level, CANH becomes continuously dominant and the affected nodes are switching to CANL operation. Further increasing of the GND shift ends again with a continuous recessive level on CANL and thus interrupts any communication. Within the previously mentioned system (see chapter 3.1.1) up to -2.1V are reached. At about -1.6V nodes are switching into single-wire mode.

9.4.7 CANL shorted to GND or BAT

Positive GND shift

Here CANH single wire communication takes place. Thus positive GND shifts lead to a continuous recessive level on CANH, if the node is shifted. Within the previously mentioned system (see chapter 9.4.1) up to $+2.0\text{V}$ are reached.

Negative GND shift

Negative GND shifts result in a continuous dominant level on CANH, if the node is shifted. This leads to a change of the transceiver into single wire mode on CANL, which is shorted. Within the previously mentioned system (see chapter 9.4.1) up to -1.6V are reached.

9.4.8 CANL shorted to VCC

Positive GND shift

In this case, the transceiver stays within differential operating mode. Because the CANH single-ended voltage is not used for failure evaluation, the communication stays active even at very high GND shifts. Similar to the case without bus failure, the communication is limited by the bit timing parameters. Within the previously mentioned system (see chapter 9.4.1) up to $+5.0\text{V}$ are reached.

Negative GND shift

At negative GND shifts, the CANH comparator becomes continuously dominant thus switching to the shorted CANL wire. Within the previously mentioned system (see chapter 9.4.1) up to -1.6V are reached.

9.4.9 Short between CANH and CANL

Positive GND shift

With a short between CANH and CANL the system operates in single wire mode via CANH. Thus the same limitation as explained within chapter 9.4.1 takes place. Within the previously mentioned system (see chapter 9.4.2) up to +2.0V are reached.

Negative GND shift

Since the system still operates in single wire mode via CANH, the same limitation as explained within chapter 9.4.2 takes place. The only difference is that here some higher loading is applied to the single ended CANH bus driver (both cables have to be driven). Thus the system cannot fully reach the same performance with respect to GND shift. Within the previously mentioned system (see chapter 9.4.1) up to -1.5V are reached.

10. Quick Reference

TJA1055T/3 Schematic: Shows a 5V regulator, 3V regulator, and CAN bus connection. Pins include INH, TXD, RXD, ERR, EN, STB, WAKE, GND, RTH, CANH, CANL, RTL. Components include capacitors C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28, C29, C30, C31, C32, C33, C34, C35, C36, C37, C38, C39, C40, C41, C42, C43, C44, C45, C46, C47, C48, C49, C50, C51, C52, C53, C54, C55, C56, C57, C58, C59, C60, C61, C62, C63, C64, C65, C66, C67, C68, C69, C70, C71, C72, C73, C74, C75, C76, C77, C78, C79, C80, C81, C82, C83, C84, C85, C86, C87, C88, C89, C90, C91, C92, C93, C94, C95, C96, C97, C98, C99, C100.

TJA1054T/TJA1055T Schematic: Shows a 5V regulator, 3V regulator, and CAN bus connection. Pins include INH, TXD, RXD, ERR, EN, STB, WAKE, GND, RTH, CANH, CANL, RTL. Components include capacitors C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28, C29, C30, C31, C32, C33, C34, C35, C36, C37, C38, C39, C40, C41, C42, C43, C44, C45, C46, C47, C48, C49, C50, C51, C52, C53, C54, C55, C56, C57, C58, C59, C60, C61, C62, C63, C64, C65, C66, C67, C68, C69, C70, C71, C72, C73, C74, C75, C76, C77, C78, C79, C80, C81, C82, C83, C84, C85, C86, C87, C88, C89, C90, C91, C92, C93, C94, C95, C96, C97, C98, C99, C100.

Timing Diagram: Shows CANL and CANH signals. Differential input voltage ranges for dominant state (1.4V to 0V) and recessive state (2.4V to -12V).

State Transition Diagram: Shows modes: Normal Mode (STB=1, EH=1), Standby Mode (STB=0, EH=0), Power-on Standby (STB=1, EH=0), Go-To-Sleep (STB=0, EH=1), Sleep (STB=0, EH=0). Transitions are triggered by events like BAT power-on, CAN bus activity, and internal flags.

Flowchart: Shows logic for BUS Failure, Wake-up Flag, PWON Flag, Pin INH, and Pin RXD. Includes conditions like V_{BAT} < V_{WAKE} and V_{BAT} < V_{WAKE} + 1.

Flowchart: Shows logic for Pin ERR and Wake-up Flag. Includes conditions like V_{BAT} < V_{WAKE} + 1 and V_{BAT} < V_{WAKE} + 1.

(1) For further EMC optimization a series resistor could be applied in case the bus timing parameters allow this additional delay caused by the additional R/C time constant.

(2) Size of capacitor depends on regulator.

(3) Size of termination resistors depends on system size. The overall system termination should be about 100 Ohms per CAN line.

11. References

- [1] International Standard ISO-11898-3
- [2] Data Sheet, CAN Transceiver TJA1055T
- [3] Data Sheet, CAN Transceiver TJA1054T / TJA1054TA
- [4] Data Sheet, CAN bus ESD protection diode in SOT23
- [5] International Standard IEC 61000-4-2, Electromagnetic Compatibility

12. Legal information

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