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General Features

- Single-package High Performance, Low Power AVR 8-bit Microcontroller with LIN Transceiver, 5V Regulator and Watchdog
- Very Low Current Consumption in Sleep Mode
- 8Kbytes/16Kbytes Flash Memory for Application Program (Atmel ATA6616/ATA6617)
- Supply Voltage Up to 40V
- Operating Voltage: 5V to 27V
- Temperature Range: T_{case} -40°C to $+125^{\circ}\text{C}$
- QFN38, 5mm \times 7mm Package

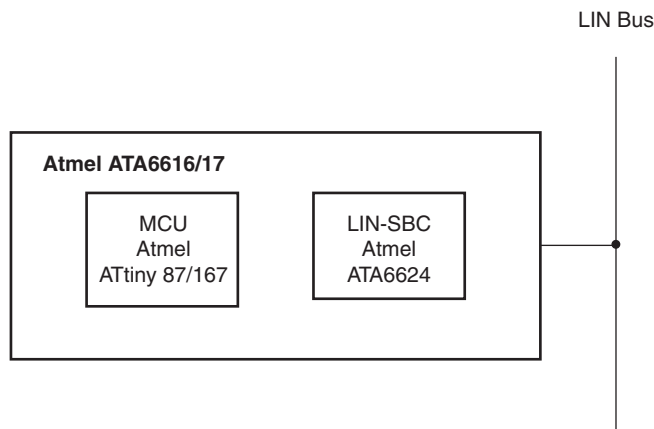
1. Description

Atmel® ATA6616/ATA6617 is a System-in-Package (SiP) product, which is particularly suited for complete LIN-bus node applications. It supports highly integrated solutions for in-vehicle LIN networks. The first chip is the LIN-system-basis-chip (LIN-SBC) ATA6624, which has an integrated LIN transceiver, a 5V regulator and a window watchdog. The second chip is an automotive microcontroller from Atmel®'s series of AVR® 8-bit microcontroller with advanced RISC architecture, the Atmel ATtiny87 with 8-Kbytes and the Atmel ATtiny167 with 16-Kbytes flash memory.

All pins of the LIN System Basis Chip as well as all pins of the AVR microcontroller are bonded out to provide customers the same flexibility for their applications as they have when using discrete parts.

In section 2 you will find the pin configuration for the complete SiP. In section 3 the LIN SBC is described, and in section 6 the AVR is described in detail.

Figure 1-1. Application Diagram



Microcontroller with LIN Transceiver, 5V Regulator and Watchdog

Atmel ATA6616 Atmel ATA6617

2. Atmel ATA6616/ATA6617 LIN System in Package Solution (SIP)

2.1 Pinning Atmel ATA6616/ATA6617

Figure 2-1. Pinning QFN38

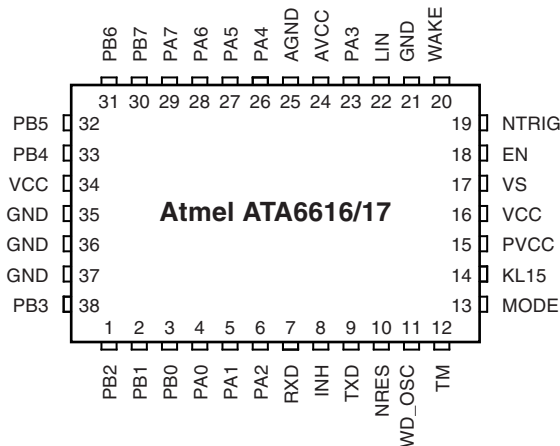


Table 2-1. Pin Description

| Pin | Symbol | Function |
|-----|-----------------------|---|
| 1 | PB2 | Port B 2 I/O line (PCINT10/OC1AV/USCK/SCL) |
| 2 | PB1 | Port B 1 I/O line (PCINT9/OC1BU/DO) |
| 3 | PB0 | Port B 0 I/O line (PCINT8/OC1AU/DI/SDA) |
| 4 | PA0 | Port A 0 I/O line (PCINT0/ADC0/RXD/RXLIN) |
| 5 | PA1 | Port A 1 I/O line (PCINT1/ADC1/TXD/TXLIN) |
| 6 | PA2 | Port A 2 I/O line (PCINT2/ADC2/OC0A/DO/MISO) |
| 7 | RXD ⁽¹⁾ | Receive data output |
| 8 | INH ⁽¹⁾ | Battery-related output for controlling an external voltage regulator |
| 9 | TXD ⁽¹⁾ | Transmit data input; active low output (strong pull down) after a local wake-up request |
| 10 | NRES ⁽¹⁾ | Output undervoltage and watchdog reset (open drain) |
| 11 | WD_OSC ⁽¹⁾ | External resistor for adjustable watchdog timing |
| 12 | TM ⁽¹⁾ | For factory testing only (tie to ground) |
| 13 | MODE ⁽¹⁾ | For debug mode: Low watchdog is on; high watchdog is off |
| 14 | KL_15 ⁽¹⁾ | Ignition detection (edge sensitive) |
| 15 | PVCC ⁽¹⁾ | 5V regulator sense input pin |
| 16 | VCC ⁽¹⁾ | 5V regulator output/driver pin |
| 17 | VS ⁽¹⁾ | Battery supply |
| 18 | EN ⁽¹⁾ | Enables the device into Normal Mode |
| 19 | NTRIG ⁽¹⁾ | Low level watchdog trigger input from microcontroller |
| 20 | WAKE ⁽¹⁾ | High voltage input for local wake-up request; if not needed connect to VS |
| 21 | GND ⁽¹⁾ | System Ground LIN-SBC |
| 22 | LIN ⁽¹⁾ | LIN bus line input/output |

Note: 1. This identifies the pins of the LIN SBC Atmel® ATA6624

Table 2-1. Pin Description (Continued)

| Pin | Symbol | Function |
|-----|----------|---|
| 23 | PA3 | Port A 3 I/O line (PCINT3/ADC3/ISRC/INT0) |
| 24 | AVCC | Analog supply voltage |
| 25 | AGND | Analog ground |
| 26 | PA4 | Port A 4 I/O line (PCINT4/ADC4/ICP1/DI/SDA/MOSI) |
| 27 | PA5 | Port A 5 I/O line (PCINT5/ADC5/T1/USCK/SCL) |
| 28 | PA6 | Port A 6 I/O line (PCINT6/ADC6/AIN0/SS) |
| 29 | PA7 | Port A 7 I/O line (PCINT7/ADC7/AIN1) |
| 30 | PB7 | Port B 7 I/O line (PCINT15/ADC10/OC1BX / RESET) |
| 31 | PB6 | Port B 6 I/O line (PCINT14/ADC9/OC1AX/INT0) |
| 32 | PB5 | Port B 5 I/O line (PCINT13/ADC8/OC1BW/XTAL2/CLKO) |
| 33 | PB4 | Port B 4 I/O line (PCINT12/OC1AW/XTAL1/CLKI) |
| 34 | VCC | AVR supply voltage |
| 35 | GND | System ground |
| 36 | GND | Ground (optional) |
| 37 | GND | Ground (optional) |
| 38 | PB3 | Port B 3 I/O line (PCINT11/OC1BV) |
| 39 | Backside | Heat slug is connected to GND |

Note: 1. This identifies the pins of the LIN SBC Atmel® ATA6624

2.2 Absolute Maximum Ratings

Table 2-2. Maximum Ratings of the SiP

Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

| Parameters | Symbol | Min. | Typ. | Max. | Unit |
|---|------------|------|------|------|------|
| HBM ESD ANSI/ESD-STM5.1 JESD22-A114 AEC-Q100 (002) | | ±3 | | | KV |
| CDM ESD STM 5.3.1 | | ±1 | | | KV |
| Machine Model ESD AEC-Q100-RevE | | ±150 | | | V |
| Storage temperature | T_s | –55 | | +150 | °C |
| Operating temperature ⁽¹⁾ | T_{case} | –40 | | +125 | °C |
| Thermal resistance junction to heat slug | R_{thjc} | | 6 | | K/W |
| Thermal resistance junction to ambient | R_{thja} | | 30 | | K/W |
| Thermal shutdown of VCC regulator | | 150 | 165 | 170 | °C |
| Thermal shutdown of LIN output | | 150 | 165 | 170 | °C |
| Thermal shutdown hysteresis | | | 10 | | °C |

Note: 1. T_{case} means the temperature of the heat slug (backside). It is mandatory that this backside temperature is ≤ 125°C in the application.

3. LIN System-basis-chip Block

3.1 Features

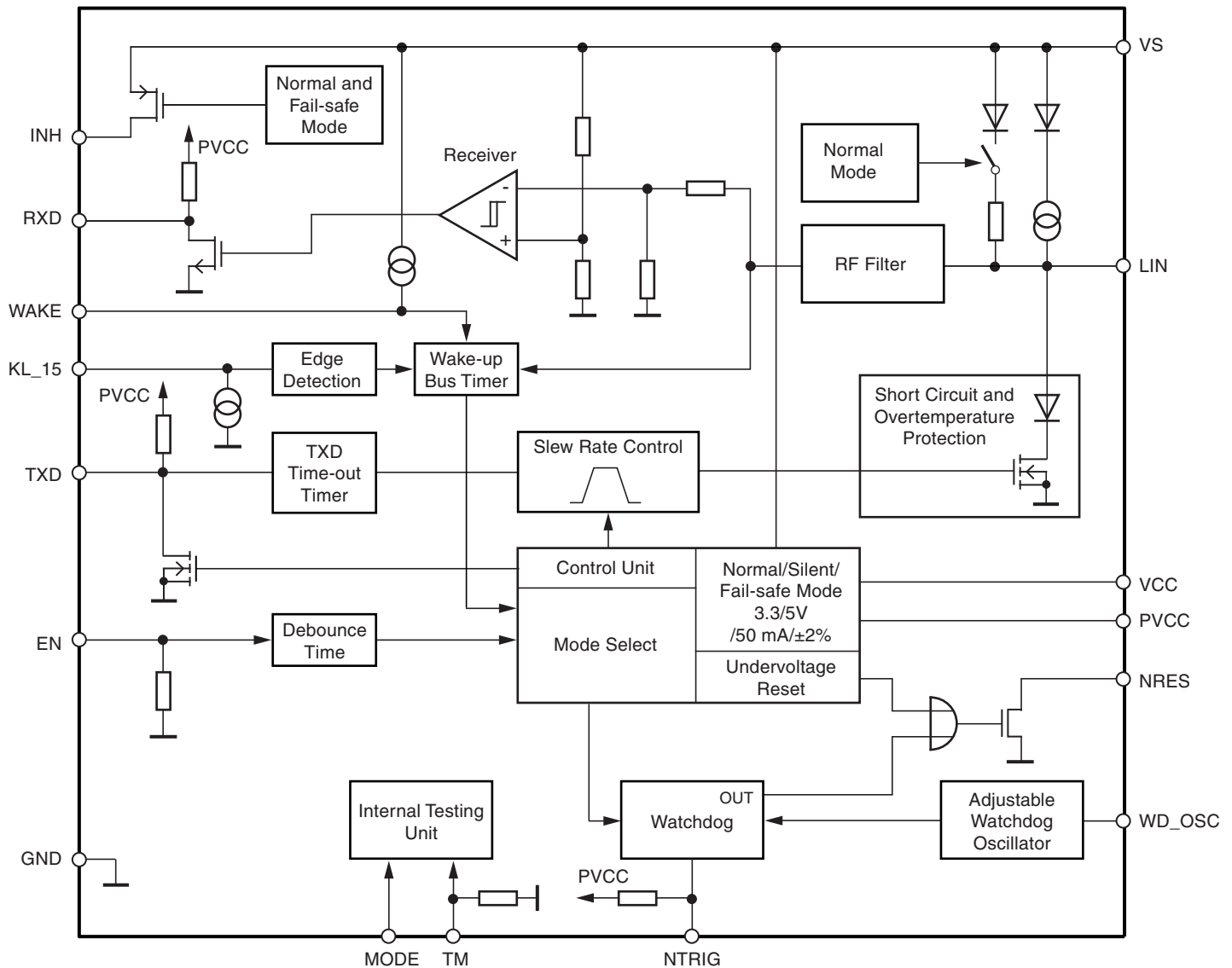
- Master and Slave Operation Possible
- Supply Voltage up to 40V
- Operating voltage $V_S = 5V$ to 27V
- Typically 10 μA Supply Current During Sleep Mode
- Typically 57 μA Supply Current in Silent Mode
- Linear Low-drop Voltage Regulator:
 - Normal, Fail-safe, and Silent Mode
 - $V_{CC} = 5.0V \pm 2\%$
 - In Sleep Mode V_{CC} is Switched Off
- VCC Undervoltage Detection (4ms Reset Time) and Watchdog Reset Logical Combined at Open Drain Output NRES
- Negative Trigger Input for Watchdog
- Boosting the Voltage Regulator Possible with an External NPN Transistor
- LIN Physical Layer According to LIN 2.0, 2.1 Specification and SAEJ2602-2
- Wake-up Capability via LIN-bus, Wake Pin, or KI_15 Pin
- INH Output to Control an External Voltage Regulator or to Switch off the Master Pull-up Resistor
- TXD Time-out Timer
- Bus Pin is Overtemperature and Short-circuit Protected versus GND and Battery
- Adjustable Watchdog Time via External Resistor
- Advanced EMC and ESD Performance
- Fulfills the OEM “Hardware Requirements for LIN in Automotive Applications Rev.1.1”
- Interference and Damage Protection According ISO7637

3.2 Description

The LIN-SBC is a fully integrated LIN transceiver, which complies with the LIN 2.0, 2.1 and SAEJ2602-2 specifications. It has a low-drop voltage regulator with a 5V/50mA output and a window watchdog.

The LIN-SBC is designed to handle the low-speed data communication in vehicles, e.g., in convenience electronics. Improved slope control at the LIN-driver ensures secure data communication up to 20kBaud. Sleep Mode and Silent Mode guarantee very low current consumption.

Figure 3-1. Block Diagram



3.3 Functional Description

3.3.1 Physical Layer Compatibility

Since the LIN physical layer is independent from higher LIN layers (e.g., the LIN protocol layer), all nodes with a LIN physical layer according to revision 2.x can be mixed with LIN physical layer nodes, which, according to older versions (i.e., LIN 1.0, LIN 1.1, LIN 1.2, LIN 1.3), are without any restrictions.

3.3.2 Supply Pin (VS)

The LIN operating voltage is $V_S = 5V$ to $27V$. An undervoltage detection is implemented to disable data transmission if V_S falls below $VS_{th} < 4V$ in order to avoid false bus messages. After switching on VS, the IC starts in Fail-safe Mode, and the voltage regulator is switched on (i.e., output capability).

The supply current is typically $10\mu A$ in Sleep Mode and $57\mu A$ in Silent Mode.

3.3.3 Ground Pin (GND)

The IC does not affect the LIN Bus in the event of GND disconnection. It is able to handle a ground shift up to 11.5% of VS. The mandatory system ground is pin 5.

3.3.4 Voltage Regulator Output Pin (VCC)

The internal 5V voltage regulator is capable of driving loads up to 50mA. It is able to supply the microcontroller and other ICs on the PCB and is protected against overload by means of current limitation and overtemperature shut-down. Furthermore, the output voltage is monitored and will cause a reset signal at the NRES output pin if it drops below a defined threshold V_{thun} . To boost the maximum load current, an external NPN transistor with its base connected to the VCC pin and its emitter connected to PVCC can be used.

3.3.5 Voltage Regulator Sense Pin (PVCC)

The PVCC is the sense input pin of the voltage regulator. For normal applications (i.e., when only using the internal output transistor), this pin is connected to the VCC pin. If an external boosting transistor is used, the PVCC pin must be connected to the output of this transistor, i.e., its emitter terminal.

3.3.6 Bus Pin (LIN)

A low-side driver with internal current limitation and thermal shutdown and an internal pull-up resistor compliant with the LIN 2.x specification are implemented. The allowed voltage range is between $-27V$ and $+40V$. Reverse currents from the LIN bus to VS are suppressed, even in the event of GND shifts or battery disconnection. LIN receiver thresholds are compatible with the LIN protocol specification. The fall time from recessive to dominant bus state and the rise time from dominant to recessive bus state are slope controlled.

3.3.7 Input/Output Pin (TXD)

In Normal Mode the TXD pin is the microcontroller interface used to control the state of the LIN output. TXD must be pulled to ground in order to have a low LIN bus. If TXD is high or unconnected (internal pull-up resistor), the LIN output transistor is turned off, and the bus is in recessive state. During Fail-safe Mode, this pin is used as output. It is current-limited to $< 8mA$, and is latched to low if the last wake-up event was from pin WAKE or KL_15.

3.3.8 TXD Dominant Time-out Function

The TXD input has an internal pull-up resistor. An internal timer prevents the bus line from being driven permanently in dominant state. If TXD is forced to low for longer than $t_{\text{DOM}} > 6\text{ms}$, the LIN-bus driver is switched to recessive state.

To reactivate the LIN-bus driver, switch TXD to high ($> 10\mu\text{s}$).

3.3.9 Output Pin (RXD)

The Output pin reports the state of the LIN bus to the microcontroller. LIN high (recessive state) is reported by a high level at RXD; LIN low (dominant state) is reported by a low level at RXD. The output has an internal pull-up resistor with typically $5\text{k}\Omega$ to VCC. The AC characteristics can be defined with an external load capacitor of 20pF .

The output is short-circuit protected. RXD is switched off in Unpowered Mode (i.e., $V_S = 0\text{V}$).

3.3.10 Enable Input Pin (EN)

The Enable Input pin controls the operation mode of the device. If EN is high, the circuit is in Normal Mode with transmission paths from TXD to LIN and from LIN to RXD both active. The VCC voltage regulator operates with $5\text{V}/50\text{ mA}$ output capability.

If EN is switched to low while TXD is still high, the device is forced to Silent Mode. No data transmission is then possible, and the current consumption is reduced to I_{VS} typ. $57\mu\text{A}$. The VCC regulator has its full functionality.

If EN is switched to low while TXD is low, the device is forced to Sleep Mode. No data transmission is possible, and the voltage regulator is switched off.

3.3.11 Wake Input Pin (WAKE)

The Wake Input pin is a high-voltage input used to wake up the device from Sleep Mode or Silent Mode. It is usually connected to an external switch in the application to generate a local wake-up. A pull-up current source, typically $10\mu\text{A}$, is implemented.

If a local wake-up is not needed for the application, connect the Wake pin directly to the VS pin.

3.3.12 Mode Input Pin (MODE)

Connect the MODE pin directly or via an external resistor to GND for normal watchdog operation. To debug the software of the connected microcontroller, connect the MODE pin to VCC and the watchdog is switched off.

3.3.13 TM Input Pin

The TM pin is used for final production measurements at Atmel. In normal application, it must always be connected to GND.

3.3.14 KL_15 Pin

The KL_15 pin is a high-voltage input used to wake up the device from Sleep or Silent Mode. It is an edge-sensitive pin (low-to-high transition). It is usually connected to ignition to generate a local wake-up in the application when the ignition is switched on. Although KL_15 pin is at high voltage (V_{Batt}), it is possible to switch the IC into Sleep or Silent Mode. Connect the KL_15 pin directly to GND if you do not need it. A debounce timer with a typical $T_{db_{KL_{15}}}$ of 160 μ s is implemented.

The input voltage threshold can be adjusted by varying the external resistor due to the input current $I_{KL_{15}}$. To protect this pin against voltage transients, a serial resistor of 47 k Ω and a ceramic capacitor of 100nF are recommended. With this RC combination you can increase the wake-up time $T_{w_{KL_{15}}}$ and, therefore, the sensitivity against transients on the ignition KL.15.

You can also increase the wake-up time using external capacitors with higher values.

3.3.15 INH Output Pin

The INH Output pin is used to switch an external voltage regulator on during Normal or Fail-safe Mode. The INH pin is switched off in Sleep or Silent Mode. It is possible to switch off the external 1k Ω master resistor via the INH pin for master node applications. The INH pin is switched off during VCC undervoltage reset.

3.3.16 Reset Output Pin (NRES)

The Reset Output pin, an open-drain output, switches to low during V_{CC} undervoltage or a watchdog failure.

3.3.17 WD_OSC Output Pin

The WD_OSC Output pin provides a typical voltage of 1.2V, which supplies an external resistor with values between 34k Ω and 120k Ω to adjust the watchdog oscillator time.

3.3.18 NTRIG Input Pin

The NTRIG Input pin is the trigger input for the window watchdog. A pull-up resistor is implemented. A negative edge triggers the watchdog. The trigger signal (low) must exceed a minimum time $t_{trigmin}$ to generate a watchdog trigger.

3.3.19 Wake-up Events from Sleep or Silent Mode

- LIN-bus
- WAKE pin
- EN pin
- KL_15

3.4 Modes of Operation

Figure 3-2. Modes of Operation

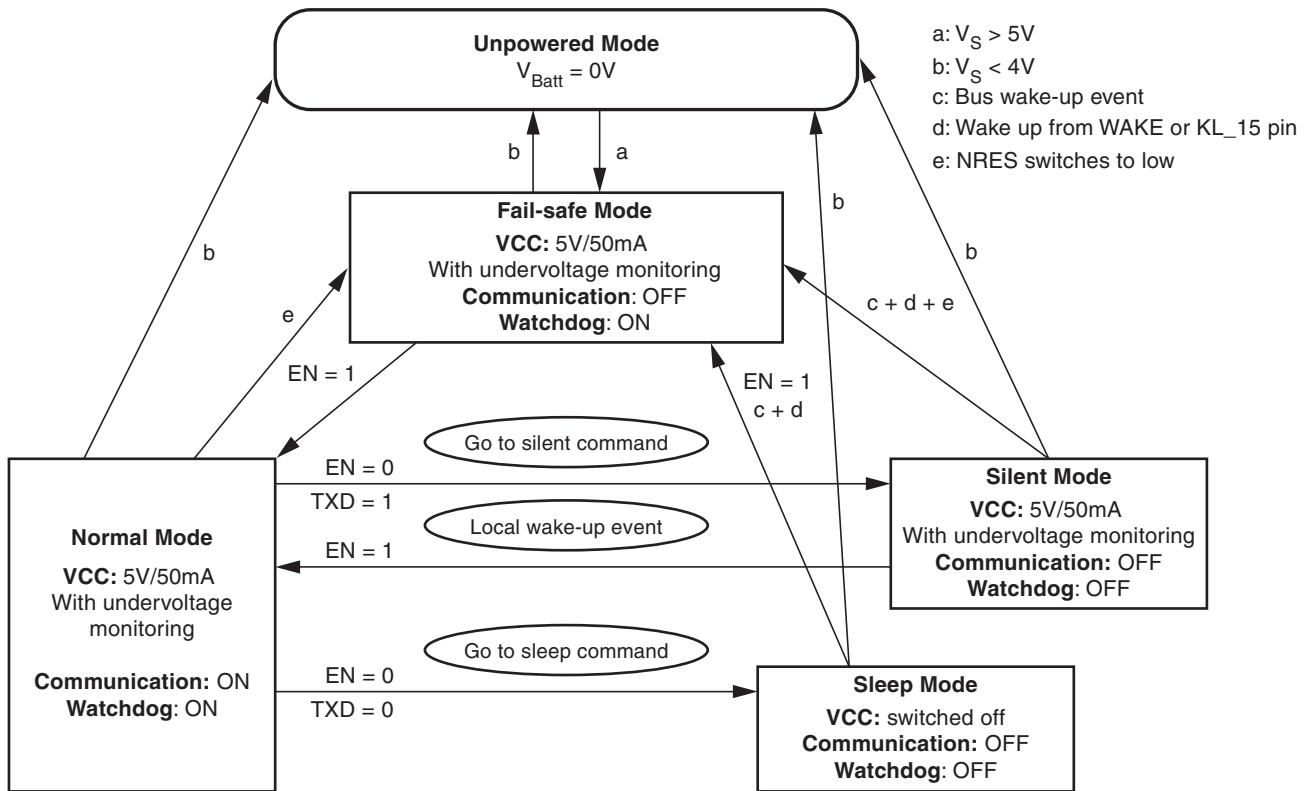


Table 3-1. Modes of Operation

| Mode of Operation | Transceiver | VCC | Watchdog | WD_OSC | INH | RXD | LIN |
|-------------------|-------------|-----|----------|--------|-----|----------------------------|---------------|
| Fail-safe | Off | 5V | On | 1.23V | On | High, except after wake up | Recessive |
| Normal | On | 5V | On | 1.23V | On | LIN depending | TXD depending |
| Silent | Off | 5V | Off | 0V | Off | High | Recessive |
| Sleep | Off | 0V | Off | 0V | Off | 0V | Recessive |

3.4.1 Normal Mode

This is the normal transmitting and receiving mode of the LIN interface in accordance with the LIN specification LIN 2.x. The voltage regulator is active and can source up to 50mA. The undervoltage detection is activated. The watchdog needs a trigger signal from NTRIG to avoid resets at NRES. If NRES is switched to low, the IC changes its state to Fail-safe Mode.

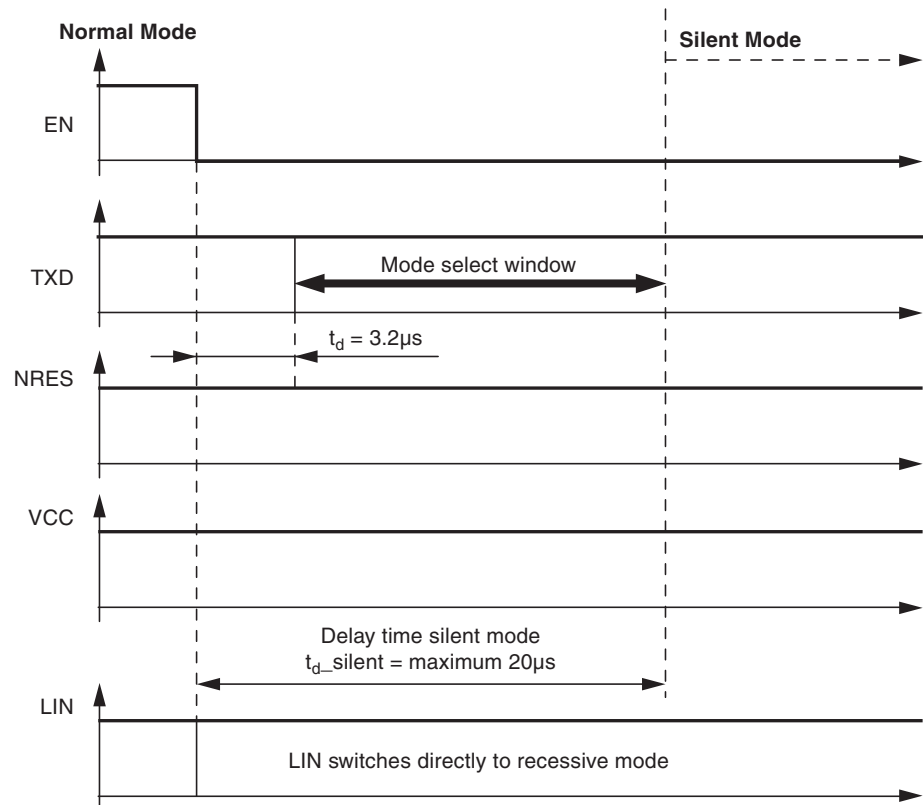
3.4.2 Silent Mode

A falling edge at EN when TXD is high switches the IC into Silent Mode. The TXD Signal has to be logic high during the Mode Select window (see [Figure 3-3 on page 10](#)). The transmission path is disabled in Silent Mode. The overall supply current from V_{Batt} is a combination of the $I_{VSSi} = 57\mu A$ plus the VCC regulator output current I_{VCC} .

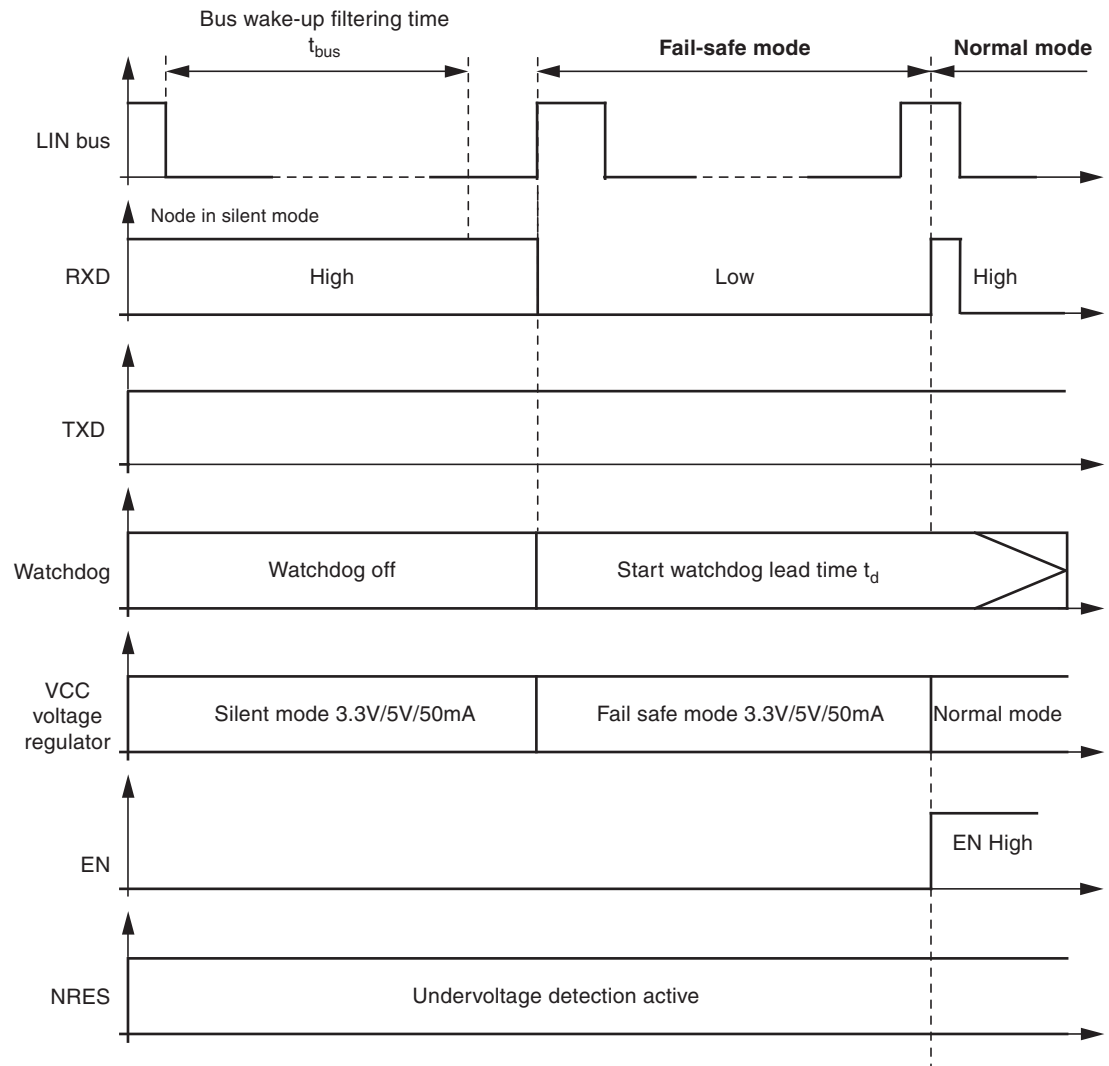
A 5V regulator with $\pm 2\%$ tolerance can source up to 50mA. The internal slave termination between the LIN pin and the VS pin is disabled in Silent Mode. Only a weak pull-up current (typically $10\mu A$) between the LIN pin and the VS pin is present. Silent Mode can be activated independently from the actual level on the LIN, WAKE, or KL_15 pins. If an undervoltage condition occurs, NRES is switched to low, and the IC changes its state to Fail-safe Mode.

A voltage less than the LIN Pre_Wake detection V_{LINL} at the LIN pin activates the internal LIN receiver and switches on the internal slave termination between the LIN pin and the VS pin.

Figure 3-3. Switch to Silent Mode



A falling edge at the LIN pin followed by a dominant bus level maintained for a certain time period (t_{bus}) and followed by rising edge at the LIN pin (see [Figure 3-4 on page 11](#)) results in a remote wake-up request. The device switches from Silent Mode to Fail-safe Mode. The remote wake-up request is indicated by a low level at the RXD pin to interrupt the microcontroller (see [Figure 3-4 on page 11](#)). EN high can be used to switch directly to Normal Mode.

Figure 3-4. LIN Wake-up from Silent Mode

3.4.3 Sleep Mode

A falling edge at EN when TXD is low switches the IC into Sleep Mode. The TXD Signal has to be logic low during the Mode Select window (Figure 3-5 on page 12). In order to avoid any influence to the LIN-pin during switching into sleep mode it is possible to switch the EN up to 3.2 μ s earlier to LOW than the TXD. Therefore, the best and easiest way are two falling edges at TXD and EN at the same time. The transmission path is disabled in Sleep Mode. The supply current $I_{VSS_{sleep}}$ from V_{Batt} is typically 10 μ A.

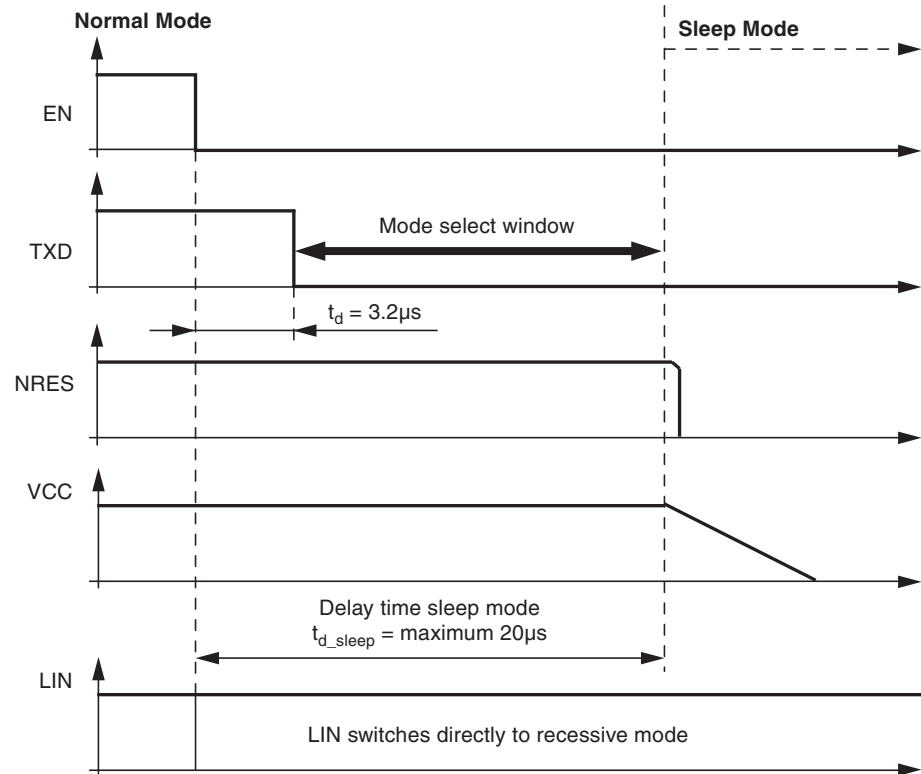
The VCC regulator is switched off. NRES and RXD are low. The internal slave termination between the LIN pin and VS pin is disabled, only a weak pull-up current (typically 10 μ A) between the LIN pin and the VS pin is present. Sleep Mode can be activated independently from the current level on the LIN, WAKE, or KL_15 pin.

A voltage less than the LIN Pre_Wake detection V_{LINL} at the LIN pin activates the internal LIN receiver and switches on the internal slave termination between the LIN pin and the V_S pin.

A falling edge at the LIN pin followed by a dominant bus level maintained for a certain time period (t_{bus}) and a following rising edge at pin LIN results in a remote wake-up request. The device switches from Sleep Mode to Fail-safe Mode.

The VCC regulator is activated, and the remote wake-up request is indicated by a low level at the RXD pin to interrupt the microcontroller (see [Figure 3-6 on page 13](#)).

Figure 3-5. Switch to Sleep Mode



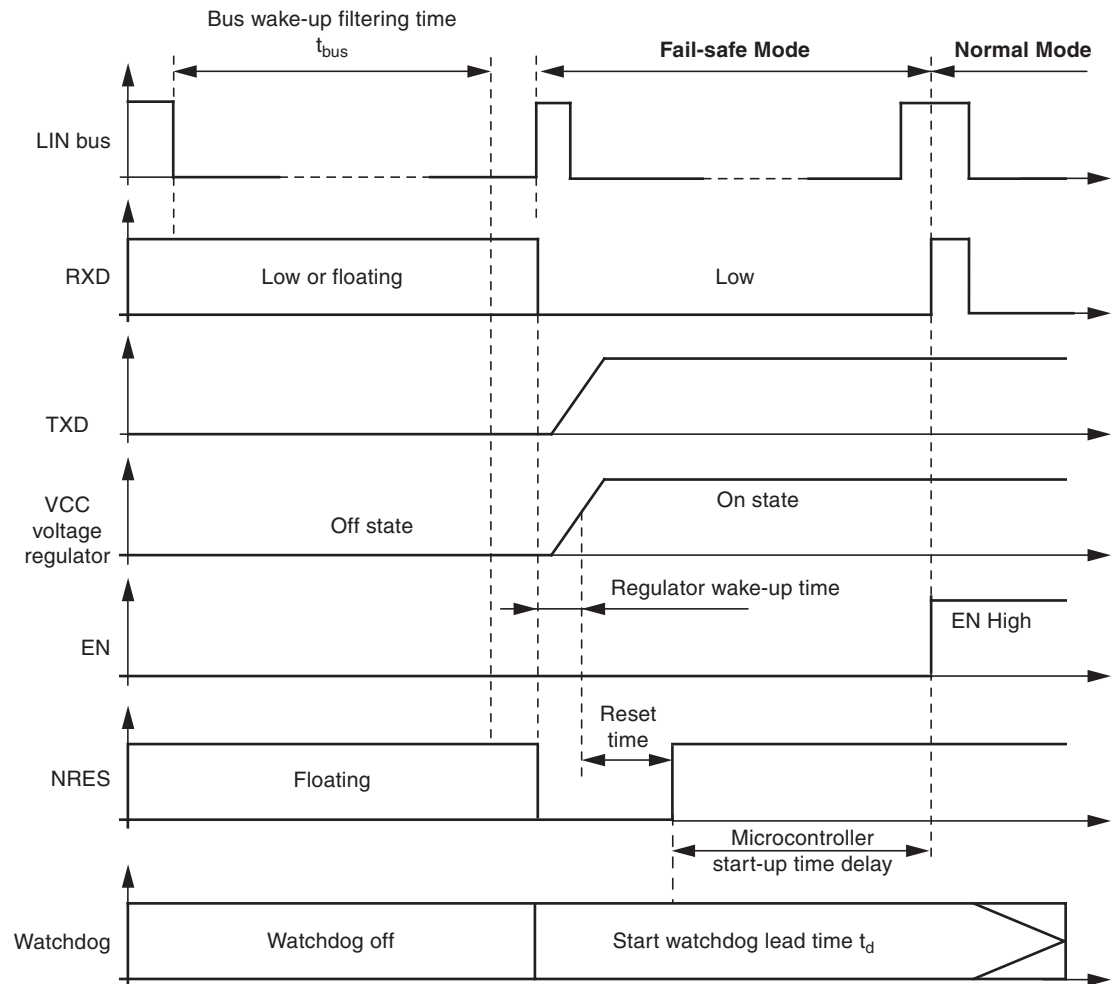
3.4.4 Fail-safe Mode

The device automatically switches to Fail-safe Mode at system power up and the voltage regulator is switched on (see [Figure 3-7 on page 16](#)). The NRES output switches to low for $t_{res} = 4ms$ and gives a reset to the microcontroller. LIN communication is switched off. The IC stays in this mode until EN is switched to high. The IC then changes to Normal Mode. A power down of V_{Batt} ($V_S < 4V$) during Silent or Sleep Mode switches the IC into Fail-safe Mode. A low at NRES switches into Fail-safe Mode directly. During Fail-safe Mode the TXD pin is an output and signals the last wake-up source.

3.4.5 Unpowered Mode

If you connect battery voltage to the application circuit, the voltage at the VS pin increases according to the block capacitor (see [Figure 3-7 on page 16](#)). After VS is higher than the VS undervoltage threshold VS_{th} , the IC mode changes from Unpowered Mode to Fail-safe Mode. The VCC output voltage reaches its nominal value after t_{VCC} . This time, t_{VCC} , depends on the VCC capacitor and the load.

The NRES is low for the reset time delay t_{reset} . During this time, t_{reset} , no mode change is possible.

Figure 3-6. LIN Wake-up from Sleep Mode

3.5 Wake-up Scenarios from Silent or Sleep Mode

3.5.1 Remote Wake-up via Dominant Bus State

A voltage less than the LIN Pre_Wake detection V_{LINL} at the LIN pin activates the internal LIN receiver.

A falling edge at the LIN pin followed by a dominant bus level V_{BUSdom} maintained for a certain time period (t_{BUS}) and a rising edge at pin LIN result in a remote wake-up request. The device switches from Silent or Sleep Mode to Fail-safe Mode. The VCC voltage regulator is/remains activated, the INH pin is switched to high, and the remote wake-up request is indicated by a low level at the RXD pin to generate an interrupt for the microcontroller. A low level at the LIN pin in the Normal Mode starts the bus wake-up filtering time, and if the IC is switched to Silent or Sleep Mode, it will receive a wake-up after a positive edge at the LIN pin.

3.5.2 Local Wake-up via Pin WAKE

A falling edge at the WAKE pin followed by a low level maintained for a certain time period (t_{WAKE}) results in a local wake-up request. The device switches to Fail-safe Mode. The local wake-up request is indicated by a low level at the RXD pin to generate an interrupt in the microcontroller and a strong pull down at TXD. When the WAKE pin is low, it is possible to switch to Silent or Sleep Mode via pin EN. In this case, the wake-up signal has to be switched to high $> 10\mu s$ before the negative edge at WAKE starts a new local wake-up request.

3.5.3 Local Wake-up via Pin KL_15

A positive edge at pin KL_15 followed by a high voltage level for a certain time period ($> t_{KL_15}$) results in a local wake-up request. The device switches into the Fail-safe Mode. The extra long wake-up time ensures that no transients at KL_15 create a wake-up. The local wake-up request is indicated by a low level at the RXD pin to generate an interrupt for the microcontroller and a strong pull down at TXD. During high-level voltage at pin KL_15, it is possible to switch to Silent or Sleep Mode via pin EN. In this case, the wake-up signal has to be switched to low $> 250\mu s$ before the positive edge at KL_15 starts a new local wake-up request. With external RC combination, the time is even longer.

3.5.4 Wake-up Source Recognition

The device can distinguish between a local wake-up request (Wake or KL_15 pins) and a remote wake-up request (via LIN bus). The wake-up source can be read on the TXD pin in Fail-safe Mode. A high level indicates a remote wake-up request (weak pull up at the TXD pin); a low level indicates a local wake-up request (strong pull down at the TXD pin). The wake-up request flag (signalled on the RXD pin) as well as the wake-up source flag (signalled on the TXD pin) is immediately reset if the microcontroller sets the EN pin to high (see [Figure 3-3 on page 10](#) and [Figure 3-4 on page 11](#)) and the IC is in Normal Mode. The last wake-up source flag is stored and signalled in Fail-safe Mode at the TXD pin.

3.5.5 Fail-safe Features

- During a short-circuit at LIN to V_{Battery} , the output limits the output current to $I_{\text{BUS_lim}}$. Due to the power dissipation, the chip temperature exceeds T_{LINoff} , and the LIN output is switched off. The chip cools down and after a hysteresis of T_{hys} , switches the output on again. RXD stays on high because LIN is high. During LIN overtemperature switch-off, the VCC regulator works independently.
- During a short-circuit from LIN to GND the IC can be switched into Sleep or Silent Mode. If the short-circuit disappears, the IC starts with a remote wake-up.
- The reverse current is very low $< 2\mu\text{A}$ at the LIN pin during loss of V_{Batt} . This is optimal behavior for bus systems where some slave nodes are supplied from battery or ignition.
- During a short circuit at VCC, the output limits the output current to $I_{\text{VCC_lin}}$. Due to undervoltage, NRES switches to low and sends a reset to the microcontroller. The IC switches into Fail-safe Mode. If the chip temperature exceeds the value T_{VCCoff} , the VCC output switches off. The chip cools down and after a hysteresis of T_{hys} , switches the output on again. Because of the Fail-safe Mode, the VCC voltage will switch on again even though EN is switched off from the microcontroller. The microcontroller can start with its normal operation.
- EN pin provides a pull-down resistor to force the transceiver into recessive mode if EN is disconnected.
- RXD pin is set floating if V_{Batt} is disconnected.
- TXD pin provides a pull-up resistor to force the transceiver into recessive mode if TXD is disconnected.
- If TXD is short-circuited to GND, it is possible to switch to Sleep Mode via ENABLE after $t_{\text{dom}} > 20\text{ms}$.
- If the WD_OSC pin has a short-circuit to GND or the resistor is disconnected, the watchdog runs with an internal oscillator and guarantees a reset after the second NTRIG signal at the latest.

3.5.6 Voltage Regulator

The voltage regulator needs an external capacitor for compensation and for smoothing the disturbances from the microcontroller. It is recommended to use an electrolytic capacitor with $C > 1.8\mu\text{F}$ and a ceramic capacitor with $C = 100\text{nF}$. The values of these capacitors can be varied by the customer, depending on the application.

The main power dissipation of the IC is created from the VCC output current I_{VCC} , which is needed for the application. In [Figure 3-8 on page 16](#) the safe operating area of the Atmel® ATA6616/ATA6617 is shown.

Figure 3-7. VCC Voltage Regulator: Ramp-up and Undervoltage Detection

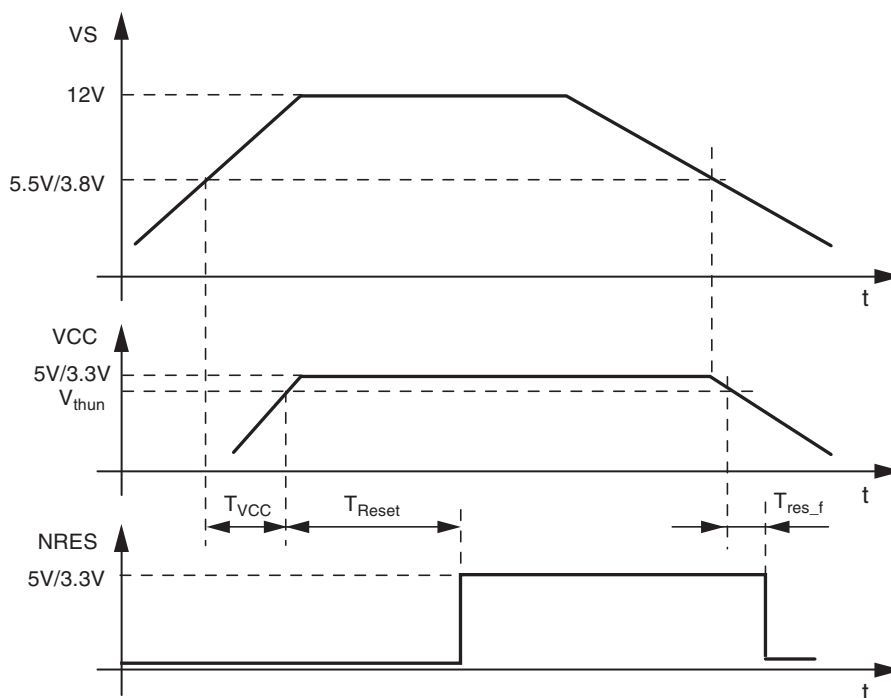
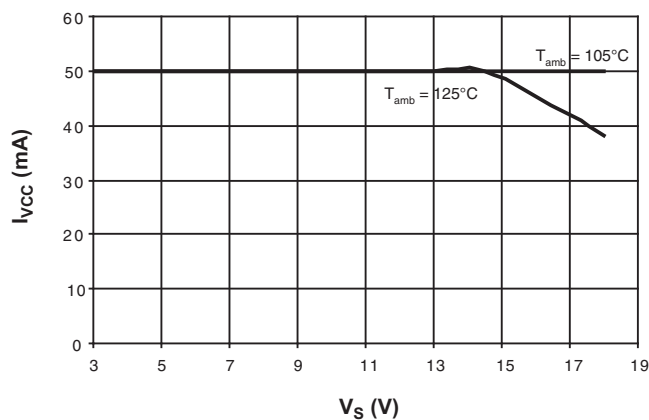


Figure 3-8. Power Dissipation: Safe Operating Area versus VCC Output Current and Supply Voltage V_S at Different Ambient Temperatures Due to $R_{thja} = 25K/W$



For programming purposes of the microcontroller it is potentially necessary to supply the V_{CC} output via an external power supply while the V_S Pin of the system basis chip is disconnected. This behavior is no problem for the system basis chip.

3.6 Watchdog

The watchdog anticipates a trigger signal from the microcontroller at the NTRIG (negative edge) input within a time window of T_{wd} . The trigger signal must exceed a minimum time $t_{trigmin} > 200ns$. If a triggering signal is not received, a reset signal will be generated at output NRES. After a watchdog reset, the IC starts with the lead time. The timing basis of the watchdog is provided by the internal oscillator. Its time period, T_{osc} , is adjustable via the external resistor R_{wd_osc} (34kΩ to 120kΩ).

During Silent or Sleep Mode the watchdog is switched off to reduce current consumption.

The minimum time for the first watchdog pulse is required after the undervoltage reset at NRES disappears. It is defined as lead time t_d . After wake up from Sleep or Silent Mode, the lead time t_d starts with the negative edge of the RXD output.

3.6.1 Typical Timing Sequence with $R_{WD_OSC} = 51k\Omega$

The trigger signal T_{wd} is adjustable between 20ms and 64ms using the external resistor R_{WD_OSC} .

For example, with an external resistor of $R_{WD_OSC} = 51k\Omega \pm 1\%$, the typical parameters of the watchdog are as follows:

$$t_{osc} = 0.405 \times R_{WD_OSC} - 0.0004 \times (R_{WD_OSC})^2 \quad (R_{WD_OSC} \text{ in } k\Omega; t_{osc} \text{ in } \mu s)$$

$$t_{OSC} = 19.6\mu s \text{ due to } 51k\Omega$$

$$t_d = 7895 \times 19.6\mu s = 155ms$$

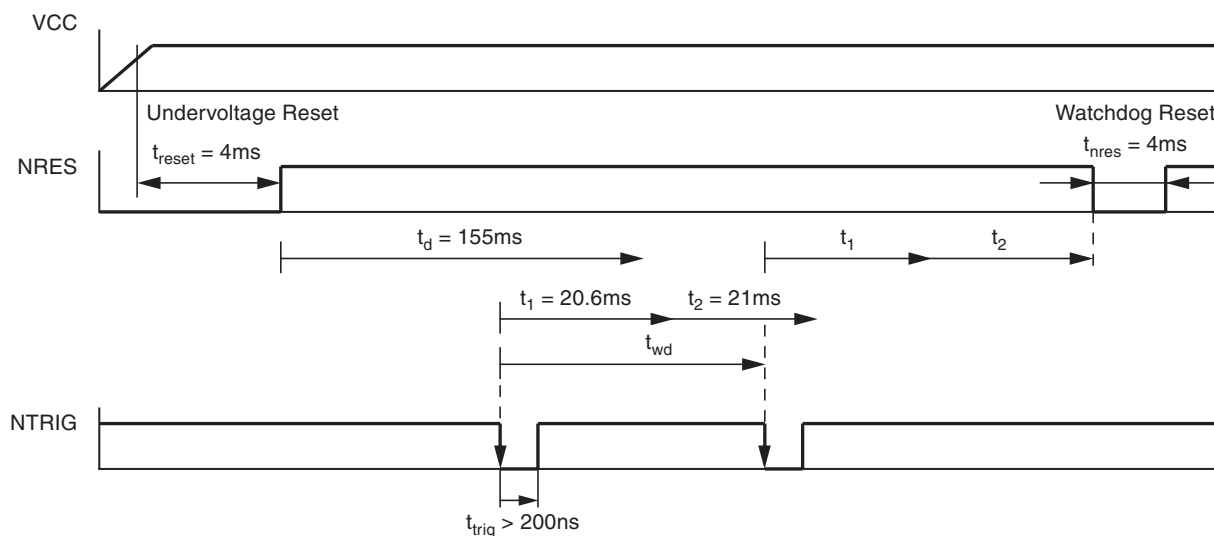
$$t_1 = 1053 \times 19.6\mu s = 20.6ms$$

$$t_2 = 1105 \times 19.6\mu s = 21.6ms$$

$$t_{nres} = \text{constant} = 4 \text{ ms}$$

After ramping up the battery voltage, the 5V regulator is switched on. The reset output NRES stays low for the time t_{reset} (typically 4ms), then it switches to high, and the watchdog waits for the trigger sequence from the microcontroller. The lead time, t_d , follows the reset and is $t_d = 155ms$. In this time, the first watchdog pulse from the microcontroller is required. If the trigger pulse NTRIG occurs during this time, the time t_1 starts immediately. If no trigger signal occurs during the time t_d , a watchdog reset with $t_{NRES} = 4ms$ will reset the microcontroller after $t_d = 155ms$. The times t_1 and t_2 have a fixed relationship between each other. A triggering signal from the microcontroller is anticipated within the time frame of $t_2 = 21.6ms$. To avoid false triggering from glitches, the trigger pulse must be longer than $t_{TRIG,min} > 200ns$. This slope serves to restart the watchdog sequence. If the triggering signal fails in this open window t_2 , the NRES output will be drawn to ground. A triggering signal during the closed window t_1 immediately switches NRES to low.

Figure 3-9. Timing Sequence with $R_{WD_OSC} = 51k\Omega$



3.6.2 Worst Case Calculation with $R_{WD_OSC} = 51 k\Omega$

The internal oscillator has a tolerance of 20%. This means that t_1 and t_2 can vary by 20%. The worst case calculation for the watchdog period t_{wd} is calculated below.

The ideal watchdog time t_{wd} is between the maximum t_1 and the minimum t_1 plus the minimum t_2 .

$$t_{1,min} = 0.8 \times t_1 = 16.5ms, t_{1,max} = 1.2 \times t_1 = 24.8ms$$

$$t_{2,min} = 0.8 \times t_2 = 17.3ms, t_{2,max} = 1.2 \times t_2 = 26ms$$

$$t_{wdmax} = t_{1min} + t_{2min} = 16.5ms + 17.3ms = 33.8ms$$

$$t_{wdmin} = t_{1max} = 24.8ms$$

$$t_{wd} = 29.3ms \pm 4.5ms (\pm 15\%)$$

A microcontroller with an oscillator tolerance of $\pm 15\%$ is sufficient to correctly supply the trigger inputs.

Table 3-2. Typical Watchdog Timings

| R_{WD_OSC} k Ω | Oscillator Period $t_{osc}/\mu s$ | Lead Time t_d/ms | Closed Window t_1/ms | Open Window t_2/ms | Trigger Period from Microcontroller t_{wd}/ms | Reset Time t_{nres}/ms |
|-----------------------------|---|--------------------------|------------------------------|-------------------------|---|--------------------------------|
| 34 | 13.3 | 105 | 14.0 | 14.7 | 19.9 | 4 |
| 51 | 19.61 | 154.8 | 20.64 | 21.67 | 29.32 | 4 |
| 91 | 33.54 | 264.80 | 35.32 | 37.06 | 50.14 | 4 |
| 120 | 42.84 | 338.22 | 45.11 | 47.34 | 64.05 | 4 |

3.7 Absolute Maximum Ratings

Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

| Parameters | Symbol | Min. | Typ. | Max. | Unit |
|---|------------|--------------------|------|--------------|------------------|
| Supply voltage V_S | V_S | −0.3 | | +40 | V |
| Pulse time $\leq 500\text{ms}$; $T_a = 25^\circ\text{C}$ Output current $I_{VCC} \leq 50\text{mA}$ | V_S | | | +40 | V |
| Pulse time $\leq 2\text{min}$; $T_a = 25^\circ\text{C}$ Output current $I_{VCC} \leq 50\text{mA}$ | V_S | | | 27 | V |
| WAKE (with 33k Ω serial resistor) KL_15 (with 50k Ω /100nF) DC voltage Transient voltage due to ISO7637 (coupling 1nF) | | −1 −150 | | +40 +100 | V V |
| INH - DC voltage | | −0.3 | | $V_S + 0.3$ | V |
| LIN - DC voltage | | −27 | | +40 | V |
| Logic pins (RxD, TxD, EN, NRES, NTRIG, WD_OSC, MODE, TM) | | −0.3 | | +5.5 | V |
| Output current NRES | I_{NRES} | | | +2 | mA |
| PVCC DC voltage VCC DC voltage | | −0.3 −0.3 | | +5.5 +6.5 | V V |
| ESD according to IBEE LIN EMC Test Spec. 1.0 following IEC 61000-4-2 - Pin VS, LIN to GND - Pin WAKE (33k Ω serial resistor) to GND | | ± 6 ± 5 | | | KV KV |
| ESD HBM following STM5.1 with 1.5k Ω 100pF - Pin VS, LIN, WAKE to GND | | ± 8 | | | KV |
| Junction temperature | T_j | −40 | | +150 | $^\circ\text{C}$ |
| Storage temperature | T_s | −55 | | +150 | $^\circ\text{C}$ |

3.8 Electrical Characteristics

5V < V_S < 27V, -40°C < T_{case} < 125°C, -40°C < T_j < 150°C, unless otherwise specified. All values refer to GND pins

| No. | Parameters | Test Conditions | Pin | Symbol | Min. | Typ. | Max. | Unit | Type* |
|----------|--|--|-----|----------------------|------|------|------------------------|------|-------|
| 1 | VS Pin | | | | | | | | |
| 1.1 | Nominal DC voltage range | | VS | V _S | 5 | | 27 | V | A |
| 1.2 | Supply current in Sleep Mode | Sleep Mode V _{LIN} > V _S - 0.5V V _S < 14V (T _j = 25°C) | VS | I _{VSSleep} | 3 | 10 | 14 | μA | A |
| | | Sleep Mode V _{LIN} > V _S - 0.5V V _S < 14V (T _j = 125°C) | VS | I _{VSSleep} | 5 | 11 | 16 | μA | A |
| 1.3 | Supply current in Silent Mode | Bus recessive V _S < 14V (T _j = 25°C) Without load at VCC | VS | I _{VSSi} | 47 | 57 | 67 | μA | A |
| | | Bus recessive V _S < 14V (T _j = 125°C) Without load at VCC | VS | I _{VSSi} | 56 | 66 | 76 | μA | A |
| 1.4 | Supply current in Normal Mode | Bus recessive V _S < 14V Without load at VCC | VS | I _{VSrec} | 0.3 | | 0.8 | mA | A |
| 1.5 | Supply current in Normal Mode | Bus dominant V _S < 14V V _{CC} load current 50 mA | VS | I _{VSdom} | 50 | | 53 | mA | A |
| 1.6 | Supply current in Fail-safe Mode | Bus recessive V _S < 14V Without load at VCC | VS | I _{VSfail} | 250 | | 550 | μA | A |
| 1.7 | V _S undervoltage threshold | | VS | V _{Sth} | 4.0 | 4.5 | 5 | V | A |
| 1.8 | VS undervoltage threshold hysteresis | | VS | V _{Sth_hys} | | 0.2 | | V | A |
| 2 | RXD Output Pin | | | | | | | | |
| 2.1 | Low-level output sink current | Normal Mode V _{LIN} = 0V V _{RXD} = 0.4V | RXD | I _{RXD} | 1.3 | 2.5 | 8 | mA | A |
| 2.2 | Low-level output voltage | I _{RXD} = 1mA | RXD | V _{RXDL} | | | 0.4 | V | A |
| 2.3 | Internal resistor to V _{CC} | | RXD | R _{RXD} | 3 | 5 | 7 | kΩ | A |
| 3 | TXD Input/Output Pin | | | | | | | | |
| 3.1 | Low-level voltage input | | TXD | V _{TXDL} | -0.3 | | +0.8 | V | A |
| 3.2 | High-level voltage input | | TXD | V _{TXDH} | 2 | | V _{CC} + 0.3V | V | A |
| 3.3 | Pull-up resistor | V _{TXD} = 0V | TXD | R _{TXD} | 125 | 250 | 400 | kΩ | A |
| 3.4 | High-level leakage current | V _{TXD} = VCC | TXD | I _{TXD} | -3 | | +3 | μA | A |
| 3.5 | Low-level output sink current at local wake-up request | Fail-safe Mode V _{LIN} = V _S V _{WAKE} = 0V V _{TXD} = 0.4V | TXD | I _{TXDwake} | 2 | 2.5 | 8 | mA | A |

*) Type means: A = 100% tested, B = 100% correlation tested, C = Characterized on samples, D = Design parameter

3.8 Electrical Characteristics (Continued)

5V < V_S < 27V, -40°C < T_{case} < 125°C, -40°C < T_j < 150°C, unless otherwise specified. All values refer to GND pins

| No. | Parameters | Test Conditions | Pin | Symbol | Min. | Typ. | Max. | Unit | Type* |
|----------|---|---|-------|-----------------------|-----------------------|------|------------------------|------|-------|
| 4 | EN Input Pin | | | | | | | | |
| 4.1 | Low-level voltage input | | EN | V _{ENL} | -0.3 | | +0.8 | V | A |
| 4.2 | High-level voltage input | | EN | V _{ENH} | 2 | | V _{CC} + 0.3V | V | A |
| 4.3 | Pull-down resistor | V _{EN} = V _{CC} | EN | R _{EN} | 50 | 125 | 200 | kΩ | A |
| 4.4 | Low-level input current | V _{EN} = 0V | EN | I _{EN} | -3 | | +3 | μA | A |
| 5 | NTRIG Watchdog Input Pin | | | | | | | | |
| 5.1 | Low-level voltage input | | NTRIG | V _{NTRIGL} | -0.3 | | +0.8 | V | A |
| 5.2 | High-level voltage input | | NTRIG | V _{NTRIGH} | 2 | | V _{CC} + 0.3V | V | A |
| 5.3 | Pull-up resistor | V _{NTRIG} = 0V | NTRIG | R _{NTRIG} | 125 | 250 | 400 | kΩ | A |
| 5.4 | High-level leakage current | V _{NTRIG} = V _{CC} | NTRIG | I _{NTRIG} | -3 | | +3 | μA | A |
| 6 | Mode Input Pin | | | | | | | | |
| 6.1 | Low-level voltage input | | MODE | V _{MODEL} | -0.3 | | +0.8 | V | A |
| 6.2 | High-level voltage input | | MODE | V _{MODEH} | 2 | | V _{CC} + 0.3V | V | A |
| 6.3 | Leakage current | V _{MODE} = V _{CC} or V _{MODE} = 0V | MODE | I _{MODE} | -3 | | +3 | μA | A |
| 7 | INH Output Pin | | | | | | | | |
| 7.1 | High-level voltage | I _{INH} = -15mA | INIT | V _{INHH} | V _S - 0.75 | | V _S | V | A |
| 7.2 | Switch-on resistance between V _S and INH | | INIT | R _{INH} | | 30 | 50 | Ω | A |
| 7.3 | Leakage current | Sleep Mode V _{INH} = 0V/27V, V _S = 27V | INIT | I _{INHL} | -3 | | +3 | μA | A |
| 8 | LIN Bus Driver: Bus Load Conditions: Load 1 (Small): 1nF, 1kΩ; Load 2 (Large): 10nF, 500Ω; R_{RXD} = 5kΩ; C_{RXD} = 20pF; Load 3 (Medium): 6.8 nF, 660Ω Characterized on Samples; 10.6 and 10.7 Specifies the Timing Parameters for Proper Operation at 20 Kbit/s, 10.8 and 10.9 at 10.4 Kbit/s. | | | | | | | | |
| 8.1 | Driver recessive output voltage | Load1/Load2 | LIN | V _{BUSrec} | 0.9 × V _S | | V _S | V | A |
| 8.2 | Driver dominant voltage | V _{VS} = 7V R _{load} = 500Ω | LIN | V _{LoSUP} | | | 1.2 | V | A |
| 8.3 | Driver dominant voltage | V _{VS} = 18V R _{load} = 500Ω | LIN | V _{HiSUP} | | | 2 | V | A |
| 8.4 | Driver dominant voltage | V _{VS} = 7.0V R _{load} = 1000Ω | LIN | V _{LoSUP_1k} | 0.6 | | | V | A |
| 8.5 | Driver dominant voltage | V _{VS} = 18V R _{load} = 1000Ω | LIN | V _{HiSUP_1k} | 0.8 | | | V | A |
| 8.6 | Pull-up resistor to V _S | The serial diode is mandatory | LIN | R _{LIN} | 20 | 30 | 60 | kΩ | A |
| 8.7 | Voltage drop at the serial diodes | In pull-up path with R _{slave} I _{SerDiode} = 10mA | LIN | V _{SerDiode} | 0.4 | | 1.0 | V | D |

*) Type means: A = 100% tested, B = 100% correlation tested, C = Characterized on samples, D = Design parameter

3.8 Electrical Characteristics (Continued)

5V < V_S < 27V, -40°C < T_{case} < 125°C, -40°C < T_j < 150°C, unless otherwise specified. All values refer to GND pins

| No. | Parameters | Test Conditions | Pin | Symbol | Min. | Typ. | Max. | Unit | Type* |
|-----------|---|---|-----|--------------------------|------------------------|----------------------|------------------------|------|-------|
| 8.8 | LIN current limitation V _{BUS} = V _{Batt_max} | | LIN | I _{BUS_LIM} | 40 | 120 | 200 | mA | A |
| 8.9 | Input leakage current at the receiver including pull-up resistor as specified | Input leakage current Driver off V _{BUS} = 0V V _{Batt} = 12V | LIN | I _{BUS_PAS_dom} | -1 | -0.35 | | mA | A |
| 8.10 | Leakage current LIN recessive | Driver off 8V < V _{Batt} < 18V 8V < V _{BUS} < 18V V _{BUS} ≥ V _{Batt} | LIN | I _{BUS_PAS_rec} | | 10 | 20 | μA | A |
| 8.11 | Leakage current when control unit disconnected from ground. Loss of local ground must not affect communication in the residual network. | GND _{Device} = V _S V _{Batt} = 12V 0V < V _{BUS} < 18V | LIN | I _{BUS_NO_gnd} | -10 | +0.5 | +10 | μA | A |
| 8.12 | Leakage current at a disconnected battery. Node has to sustain the current that can flow under this condition. Bus must remain operational under this condition. | V _{Batt} disconnected V _{SUP_Device} = GND 0V < V _{BUS} < 18V | LIN | I _{BUS_NO_bat} | | 0.1 | 2 | μA | A |
| 9 | LIN Bus Receiver | | | | | | | | |
| 9.1 | Center of receiver threshold | V _{BUS_CNT} = (V _{th_dom} + V _{th_rec})/2 | LIN | V _{BUS_CNT} | 0.475 × V _S | 0.5 × V _S | 0.525 × V _S | V | A |
| 9.2 | Receiver dominant state | V _{EN} = 5V | LIN | V _{BUSdom} | | | 0.4 × V _S | V | A |
| 9.3 | Receiver recessive state | V _{EN} = 5V | LIN | V _{BUSrec} | 0.6 × V _S | | | V | A |
| 9.4 | Receiver input hysteresis | V _{hys} = V _{th_rec} - V _{th_dom} | LIN | V _{BUShys} | 0.028 × V _S | 0.1 × V _S | 0.175 × V _S | V | A |
| 9.5 | Pre_Wake detection LIN High-level input voltage | | LIN | V _{LINH} | V _S - 2V | | V _S + 0.3V | V | A |
| 9.6 | Pre_Wake detection LIN Low-level input voltage | Activates the LIN receiver | LIN | V _{LINL} | -27 | | V _S - 3.3V | V | A |
| 10 | Internal Timers | | | | | | | | |
| 10.1 | Dominant time for wake-up via LIN bus | V _{LIN} = 0V | LIN | t _{bus} | 30 | 90 | 150 | μs | A |
| 10.2 | Time delay for mode change from Fail-safe into Normal Mode via EN pin | V _{EN} = 5V | EN | t _{norm} | 5 | 15 | 20 | μs | A |
| 10.3 | Time delay for mode change from Normal Mode to Sleep Mode via EN pin | V _{EN} = 0V | EN | t _{sleep} | 2 | 7 | 12 | μs | A |

*) Type means: A = 100% tested, B = 100% correlation tested, C = Characterized on samples, D = Design parameter

3.8 Electrical Characteristics (Continued)

5V < V_S < 27V, -40°C < T_{case} < 125°C, -40°C < T_j < 150°C, unless otherwise specified. All values refer to GND pins

| No. | Parameters | Test Conditions | Pin | Symbol | Min. | Typ. | Max. | Unit | Type* |
|-------|---|---|------|--|-------|------|-------------|--------|-------|
| 10.4 | TXD dominant time-out time | V _{TXD} = 0V | TXD | t _{dom} | 6 | 13 | 20 | ms | A |
| 10.5 | Time delay for mode change from Silent Mode into Normal Mode via EN | V _{EN} = 5V | EN | t _{s_n} | 5 | 15 | 40 | μs | A |
| 10.6 | Duty cycle 1 | TH _{Rec(max)} = 0.744 × V _S TH _{Dom(max)} = 0.581 × V _S V _S = 7.0V to 18V t _{Bit} = 50μs D1 = t _{bus_rec(min)} / (2 × t _{Bit}) | LIN | D1 | 0.396 | | | | A |
| 10.7 | Duty cycle 2 | TH _{Rec(min)} = 0.422 × V _S TH _{Dom(min)} = 0.284 × V _S V _S = 7.6V to 18V t _{Bit} = 50μs D2 = t _{bus_rec(max)} / (2 × t _{Bit}) | LIN | D2 | | | 0.581 | | A |
| 10.8 | Duty cycle 3 | TH _{Rec(max)} = 0.778 × V _S TH _{Dom(max)} = 0.616 × V _S V _S = 7.0V to 18V t _{Bit} = 96μs D3 = t _{bus_rec(min)} / (2 × t _{Bit}) | LIN | D3 | 0.417 | | | | A |
| 10.9 | Duty cycle 4 | TH _{Rec(min)} = 0.389 × V _S TH _{Dom(min)} = 0.251 × V _S V _S = 7.6V to 18V t _{Bit} = 96μs D4 = t _{bus_rec(max)} / (2 × t _{Bit}) | LIN | D4 | | | 0.590 | | A |
| 10.10 | Slope time falling and rising edge at LIN | V _S = 7.0V to 18V | LIN | t _{SLOPE_fall} t _{SLOPE_rise} | 3.5 | | 22.5 | μs | A |
| 11 | Receiver Electrical AC Parameters of the LIN Physical Layer LIN Receiver, RXD Load Conditions C_{RXD} = 20pF | | | | | | | | |
| 11.1 | Propagation delay of receiver (Figure 3-10 on page 26) | V _S = 7.0V to 18V t _{rx_pd} = max(t _{rx_pdr} , t _{rx_pdf}) | RXD | t _{rx_pd} | | | 6 | μs | A |
| 11.2 | Symmetry of receiver propagation delay rising edge minus falling edge | V _S = 7.0V to 18V t _{rx_sym} = t _{rx_pdr} - t _{rx_pdf} | RXD | t _{rx_sym} | -2 | | +2 | μs | A |
| 12 | NRES Open Drain Output Pin | | | | | | | | |
| 12.1 | Low-level output voltage | V _S ≥ 5.5V I _{NRES} = 1mA I _{NRES} = 250μA | NRES | V _{NRESL} | | | 0.2 0.14 | V V | A |
| 12.2 | Low-level output low | 10kΩ to V _{CC} V _{CC} = 0V | NRES | V _{NRESLL} | | | 0.2 | V | A |
| 12.3 | Undervoltage reset time | V _S ≥ 5.5V C _{NRES} = 20pF | NRES | t _{reset} | 2 | 4 | 6 | ms | A |
| 12.4 | Reset debounce time for falling edge | V _S ≥ 5.5V C _{NRES} = 20pF | NRES | t _{res_f} | 1.5 | | 10 | μs | A |

*) Type means: A = 100% tested, B = 100% correlation tested, C = Characterized on samples, D = Design parameter

3.8 Electrical Characteristics (Continued)

5V < V_S < 27V, -40°C < T_{case} < 125°C, -40°C < T_j < 150°C, unless otherwise specified. All values refer to GND pins

| No. | Parameters | Test Conditions | Pin | Symbol | Min. | Typ. | Max. | Unit | Type* |
|-----------|--|--|--------|----------------------------------|---------------------|------|-----------------------|--------|-------|
| 13 | Watchdog Oscillator | | | | | | | | |
| 13.1 | Voltage at WD_OSC in Normal Mode | I _{WD_OSC} = -200μA V _{VS} ≥ 4V | WD_OSC | V _{WD_OSC} | 1.13 | 1.23 | 1.33 | V | A |
| 13.2 | Possible values of resistor | | WD_OSC | R _{OSC} | 34 | | 120 | kΩ | A |
| 13.3 | Oscillator period | R _{OSC} = 34kΩ | | t _{OSC} | 10.65 | 13.3 | 15.97 | μs | A |
| 13.4 | Oscillator period | R _{OSC} = 51kΩ | | t _{OSC} | 15.68 | 19.6 | 23.52 | μs | A |
| 13.5 | Oscillator period | R _{OSC} = 91kΩ | | t _{OSC} | 26.83 | 33.5 | 40.24 | μs | A |
| 13.6 | Oscillator period | R _{OSC} = 120kΩ | | t _{OSC} | 34.2 | 42.8 | 51.4 | μs | A |
| 14 | Watchdog Timing Relative to t_{osc} | | | | | | | | |
| 14.1 | Watchdog lead time after reset | | | t _d | | 7895 | | cycles | A |
| 14.2 | Watchdog closed window | | | t ₁ | | 1053 | | cycles | A |
| 14.3 | Watchdog open window | | | t ₂ | | 1105 | | cycles | A |
| 14.4 | Watchdog reset time NRES | | NRES | t _{nres} | 3.2 | 4 | 4.8 | ms | A |
| 15 | KL_15 Pin | | | | | | | | |
| 15.1 | High-level input voltage R _V = 47 kΩ | Positive edge initializes a wake-up | KL_15 | V _{KL_15H} | 4 | | V _S + 0.3V | V | A |
| 15.2 | Low-level input voltage R _V = 47 kΩ | | KL_15 | V _{KL_15L} | -1 | | +2 | V | A |
| 15.3 | KL_15 pull-down current | V _S < 27V V _{KL_15} = 27V | KL_15 | I _{KL_15} | | 50 | 65 | μA | A |
| 15.4 | Internal debounce time | Without external capacitor | KL_15 | T _{db} _{KL_15} | 80 | 160 | 250 | μs | A |
| 15.5 | KL_15 wake-up time | R _V = 47kΩ, C = 100nF | KL_15 | T _w _{KL_15} | 0.4 | 2 | 4.5 | ms | C |
| 16 | WAKE Pin | | | | | | | | |
| 16.1 | High-level input voltage | | WAKE | V _{WAKEH} | V _S - 1V | | V _S + 0.3V | V | A |
| 16.2 | Low-level input voltage | Initializes a wake-up signal | WAKE | V _{WAKEL} | -1 | | V _S - 3.3V | V | A |
| 16.3 | WAKE pull-up current | V _S < 27V V _{WAKE} = 0V | WAKE | I _{WAKE} | -30 | -10 | | μA | A |
| 16.4 | High-level leakage current | V _S = 27V V _{WAKE} = 27V | WAKE | I _{WAKEL} | -5 | | +5 | μA | A |
| 16.5 | Time of low pulse for wake-up via WAKE pin | V _{WAKE} = 0V | WAKE | I _{WAKEL} | 30 | 70 | 150 | μs | A |

*) Type means: A = 100% tested, B = 100% correlation tested, C = Characterized on samples, D = Design parameter

3.8 Electrical Characteristics (Continued)

5V < V_S < 27V, -40°C < T_{case} < 125°C, -40°C < T_j < 150°C, unless otherwise specified. All values refer to GND pins

| No. | Parameters | Test Conditions | Pin | Symbol | Min. | Typ. | Max. | Unit | Type* |
|-----------|--|---|-------------------------|----------------------------------|---------------------------------|------|------|------|-------|
| 18 | VCC Voltage Regulator, PVCC = VCC | | | | | | | | |
| 18.1 | Output voltage VCC | 5.5V < V _S < 18V (0mA to 50mA) | VCC | VCC _{nor} | 4.9 | | 5.1 | V | A |
| 18.2 | Output voltage VCC at low V _S | 4V < V _S < 5.5V | VCC | VCC _{low} | V _S - V _D | | 5.1 | V | A |
| 18.3 | Regulator drop voltage | V _S > 4V I _{VCC} = -20mA | V _S , VCC | V _{D1} | | | 250 | mV | A |
| 18.4 | Regulator drop voltage | V _S > 4V I _{VCC} = -50mA | V _S , VCC | V _{D2} | | 400 | 600 | mV | A |
| 18.5 | Regulator drop voltage | V _S > 3.3V I _{VCC} = -15mA | V _S , VCC | V _{D3} | | | 200 | mV | A |
| 18.6 | Line regulation | 5.5V < V _S < 18V | VCC | VCC _{line} | | | 1 | % | A |
| 18.7 | Load regulation | 5mA < I _{VCC} < 50mA | VCC | VCC _{load} | | 0.5 | 2 | % | A |
| 18.8 | Power supply ripple rejection | 10Hz to 100kHz C _{VCC} = 10μF V _S = 14V, I _{VCC} = -15mA | VCC | | 50 | | | dB | A |
| 18.9 | Output current limitation | V _S > 5.5V | VCC | I _{VCClim} | -240 | -130 | | mA | A |
| 18.10 | Load capacity | 0.2Ω < ESR < 5Ω at 100kHz | VCC | V _{thunN} | 1.8 | 10 | | μF | D |
| 18.11 | VCC undervoltage threshold | Referred to VCC V _S > 5.5V | VCC | V _{thunN} | 4.2 | | 4.8 | V | A |
| 18.12 | Hysteresis of undervoltage threshold | Referred to VCC V _S > 5.5V | VCC | V _{hys} _{thun} | | 250 | | mV | A |
| 18.13 | Ramp-up time V _S > 5.5V to V _{CC} = 5V | C _{VCC} = 2.2μF I _{load} = -5mA at VCC | VCC | t _{VCC} | | 130 | 300 | μs | A |

*) Type means: A = 100% tested, B = 100% correlation tested, C = Characterized on samples, D = Design parameter