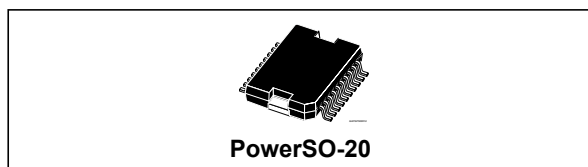


Low $R_{DS(on)}$ SPI controlled H-Bridge

Datasheet - production data



- Advanced mold and frame designs for Superior resilience to harsh environment (acceleration, EMI, thermal, humidity)
- Single Fabrication, Assembly and Test site
- Dual internal production source capability

Features

- Programmable current regulation peak threshold by SPI up to 8.6 A typ.
- Operating battery supply voltage 4.0 V to 28 V
- Operating V_{dd} supply voltage 4.5 V to 5.5 V
- All pins withstand 19 V, V_s and output pins withstand 40 V
- Full path R_{on} from 100 m Ω (at $T_j = -40$ °C) to 300 m Ω (at $T_j = 150$ °C)
- Logic inputs TTL/CMOS-compatible
- Operating frequency up to 20 kHz
- 16-bit SPI interface for configuration/diagnostics, daisy chain capability
- Over temperature and short circuit protection
- V_s undervoltage disable function
- V_{dd} undervoltage and overvoltage protection
- V_{dd} overvoltage detection
- Open-load detection in ON condition
- Full diagnostics in OFF state
- Enable and disable input
- Low stand by current (<10 μ A)
- Voltage and current slew-rate control for low EMI, programmable through SPI
- Aerospace and Defense features
 - Dedicated traceability and part marking
 - Production parts approval documents available
 - Adapted Extended life time and obsolescence management
 - Extended Product Change Notification process
 - Designed and manufactured to meet sub ppm quality goals

Application

All types of resistive, inductive and capacitive loads in Aerospace and Defense applications.

Description

The RL9958 is an SPI controlled H-Bridge, designed for the control of DC and stepper motors in safety critical applications and under extreme environmental conditions.

The H-Bridge is protected against over temperature, short circuits and has an undervoltage lockout for all the supply voltages V_s and V_{dd} , and for overvoltage on V_{dd} . All malfunctions cause the output stages to go tristate.

Detailed failure diagnostics on each channel is provided via SPI: short circuit to battery, short circuit to ground, short circuit overload, over temperature.

Open-load can be detected in ON condition, for the widest application ranges. Current regulation threshold can be set by SPI from 2.5 A to 8.6 A (Typ.), in 4 steps. Guaranteed accuracy is ± 10 % on all temp range, using an external reference resistor with 1% accuracy over all temp range.

Current limitation threshold is linearly reduced by temperature over 165 °C and a thermal warning bit is set by SPI. The H-Bridge contains integrated free-wheel diodes. In case of free-wheeling condition, the low side transistor is switched on in parallel of its diode to reduce power dissipation.

A multiple wire bonding technique, as well as ST proprietary package design is making RL9958 compatible with several power packages, for maximum flexibility:

PowerSO-20 package (medium power, JEDEC standard MO166).

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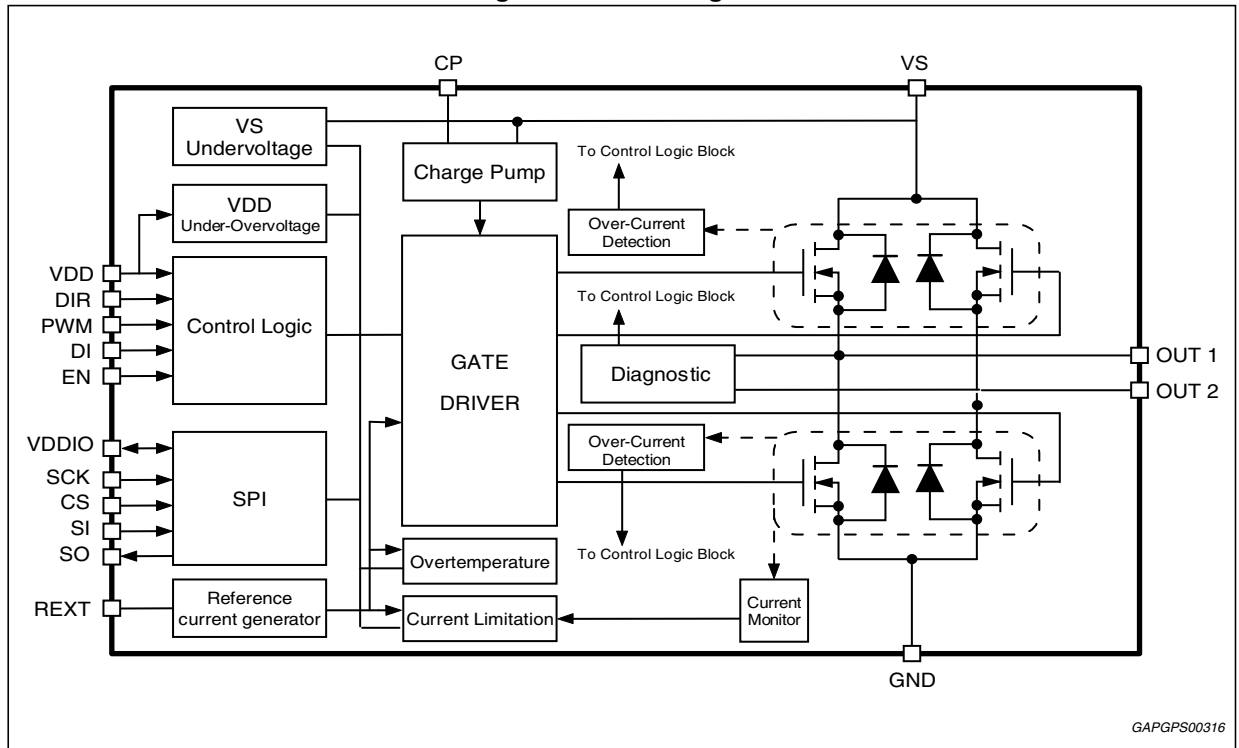
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1 Block diagram

Figure 1. Block diagram



2 Pins description

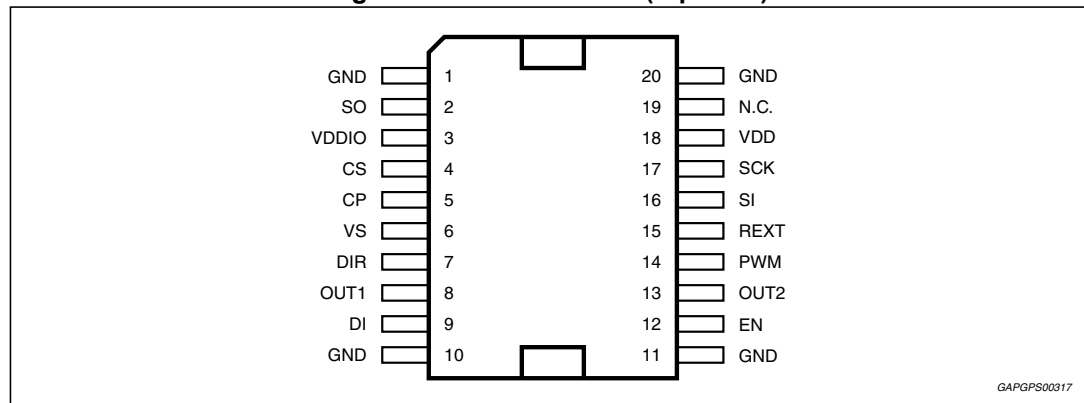
2.1 Pins function

The exposed slug must be soldered on the PCB and connected to GND.

Table 1. PowerSO-20 pin function

| Pin N° | Name | Description |
|--------|-------|---|
| 1 | GND | Ground |
| 2 | SO | Serial out |
| 3 | VDDIO | Supply voltage for SPI |
| 4 | CS | Chip select |
| 5 | CP | Charge pump |
| 6 | VS | Supply voltage |
| 7 | DIR | Direction input |
| 8 | OUT1 | Output 1 |
| 9 | DI | Disable |
| 10 | GND | Ground |
| 11 | GND | Ground |
| 12 | EN | Enable |
| 13 | OUT2 | Output 2 |
| 14 | PWM | PWM input |
| 15 | REXT | External reference resistor |
| 16 | SI | Serial in |
| 17 | SCK | SPI clock |
| 18 | VDD | Supply voltage |
| 19 | N.C. | Not connected (To be connected to GND on the PCB) |
| 20 | GND | Ground |

Figure 2. Pin connection (top view)



3 Device description

3.1 Supply range

The RL9958 has an operating supply range from "Vs_uv" (battery monitoring) up to 28 V. However, the device is tested until 16 V; the functionality of the device is guaranteed until 28 V. The absolute maximum rating is defined to 40 V DC.

3.2 Control inputs

The bridge is controlled by the Inputs PWM, DIR, EN and DI.
 All the digital inputs and outputs of the RL9958 are compatible with 3.3 V and 5 V CMOS.
 The power stages output OUT1 and OUT2 are controlled by the direct inputs DIR and PWM as given in [Table 2](#). The DIR input gives the direction of output current, while the PWM input controls whether the current is increased or reduced.

3.2.1 DI and EN inputs

The pin DI is internally pulled-up and high active. When DI is active (set to HIGH), the bridge is set to tristate, whatever the state of the DIR and PWM inputs. All the data stored in SPI registers are not reset and SPI communication with the MCU is still possible. When DI is inactive (set to LOW), the bridge is controlled by the DIR and PWM inputs.

The pin EN is internally pulled down and high active. When EN is inactive (set to LOW), the bridge is set to tri-state, whatever the state of the DIR and PWM inputs. All the data stored in SPI registers are not reset and SPI communication with the MCU is still possible. When EN is active (set to HIGH), the bridge is controlled by the DIR and PWM inputs. The coding is performed as shown in the next table. The state of the bridge is transferred in the diagnostic register in a bit called "ACT".

Table 2. Control pins EN, DI

| EN | DI | Bit "ACT" | Bridge status |
|----|----|-----------|---------------|
| 0 | 0 | 0 | Tri-state |
| 0 | 1 | 0 | Tri-state |
| 1 | 0 | 1 | On-state |
| 1 | 1 | 0 | Tri-state |

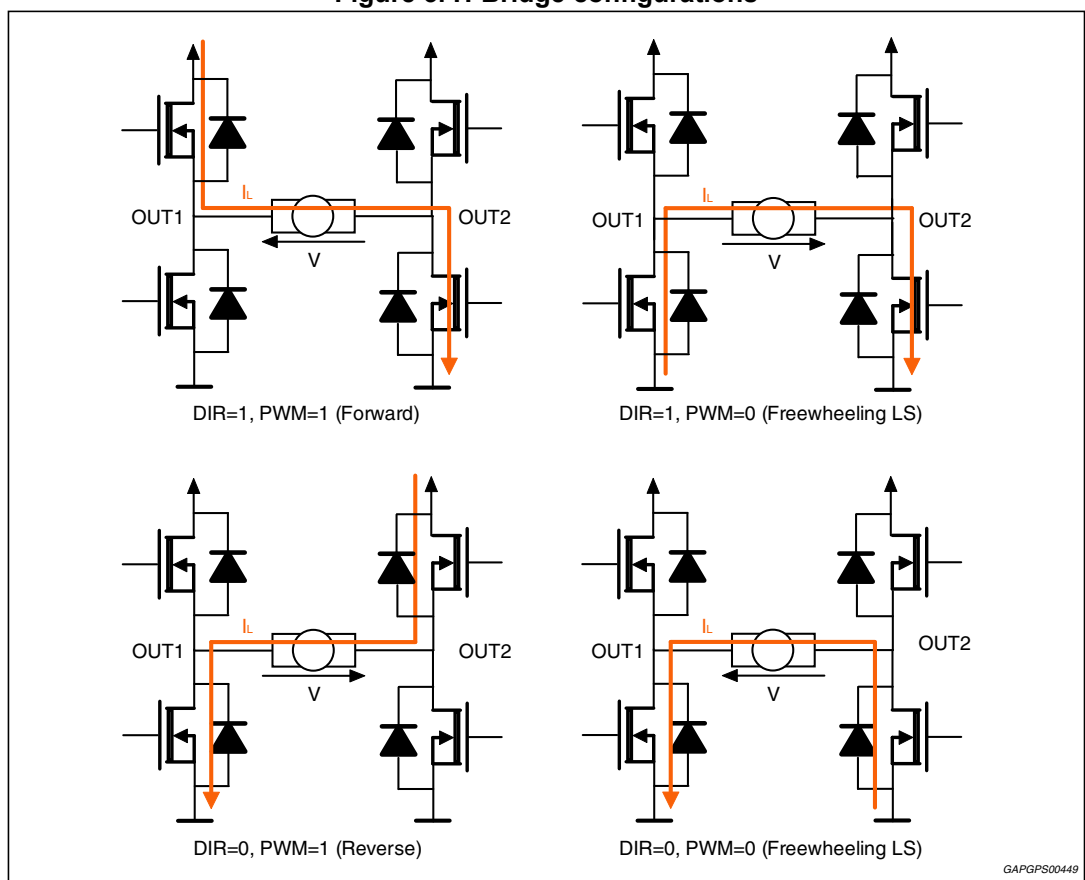
3.2.2 DIR and PWM inputs

The pins DIR and PWM are internally pulled down. The bridge is controlled by these two inputs according to the table below.

Table 3. Control pins DIR, PWM

| DIR | PWM | OUT1 | OUT2 | Bridge Status |
|-----|-----|------|------|------------------|
| H | H | H | L | Forward |
| L | L | L | L | Freewheeling Low |
| L | H | L | H | Reverse |
| H | L | L | L | Freewheeling low |

Figure 3. H-Bridge configurations



The outputs can be disabled (set to tri-state) by the Disable and Enable inputs DI and EN. Input DI has an internal pull-up. Input EN has an internal pull-down. During freewheeling phase, an active freewheeling on the Low-Side MOS is automatically set, switching ON the power transistor in parallel to the internal freewheeling diode.

3.3 Serial peripheral interface (SPI)

The SPI is used for bidirectional communication with a control unit, allowing IC configuration, diagnosis and identification. RL9958 can also be used in daisy-chain configuration (number of device in the daisy chain is not limited).

The SPI interface of RL9958 is a slave SPI interface: the master is the μ C which provides CS and SCK to RL9958.

Transfer format uses 16 bits word in case of single device configuration and multiple of 16 bits word in case of daisy chain configuration.

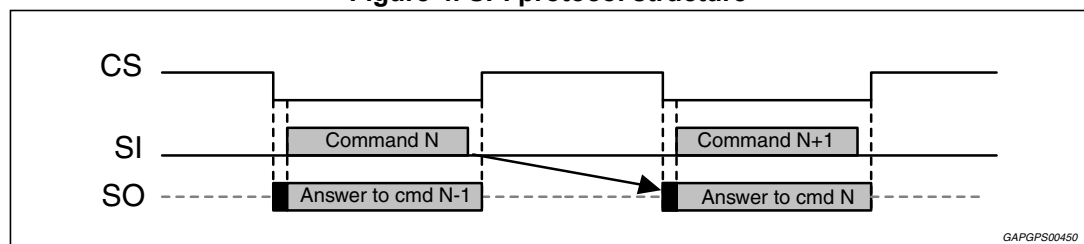
The first answer after Power-ON-Reset is the IC identifier.

A command sent by the μ C during transfer N is answered during transfer N+1. SO is clocked on SCK rising edge. SI is sampled on falling edge. When CS = '1' and during power-ON reset, SO is in tri-state. Otherwise, the SPI interface is always active.

Settings made by the SPI control word become active at the end of the SPI transmission and remain valid until a different control word is transmitted or a power on reset occurs.

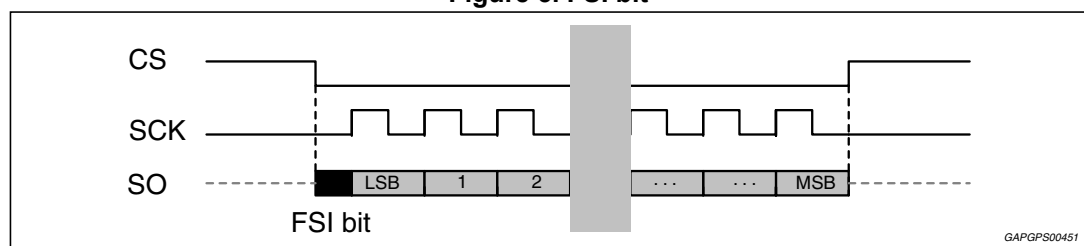
At each SPI transmission, the diagnosis bits as currently valid in the error logic are transmitted. Details on diagnosis are described in [Section 5](#).

Figure 4. SPI protocol structure



Between CS falling edge and SCK rising edge, an internal signal called "FSI bit" is set asynchronously on SO output. This can be useful to have internal information on the device without stimulating the SCK clock. The definition of the FSI bit is presented in the diagnostics chapter.

Figure 5. FSI bit



Except the Enable / Disable bit ("ACT" pin), all the bits of diagnosis register are latched and can be released by:

- Diagnosis register read by SPI
- Power-On-Reset condition.

The coding for the Configuration and Diagnosis Registers is reported in the table below.

Table 4. Configuration protocol (CFG_REG)

| Bit | Name | Description | Config. value after reset |
|---------|---------|-----------------------------------|---------------------------|
| 0 - LSB | RES | Reserved | — |
| 1 | DR | Diagnostic Reset Bit | 0 |
| 2 | CL_1 | Bit1 for Regulation Current Level | 0 |
| 3 | CL_2 | Bit2 for Regulation Current Level | 1 |
| 4 | RES | Reserved | — |
| 5 | RES | Reserved | — |
| 6 | RES | Reserved | — |
| 7 | RES | Reserved | — |
| 8 | VSR | Voltage Slew Rate Control Value | 0 |
| 9 | ISR | Current Slew Rate Control Value | 0 |
| 10 | ISR_DIS | Current Slew Rate Control Disable | 0 |
| 11 | OL_ON | Open Load in ON state Enable | 0 |
| 12 | RES | Reserved | — |
| 13 | RES | Reserved | — |
| 14 | 0 | "0" to be written | — |
| 15-MSB | 0 | "0" to be written | — |

Table 5. Diagnosis protocol (DIA_REG)

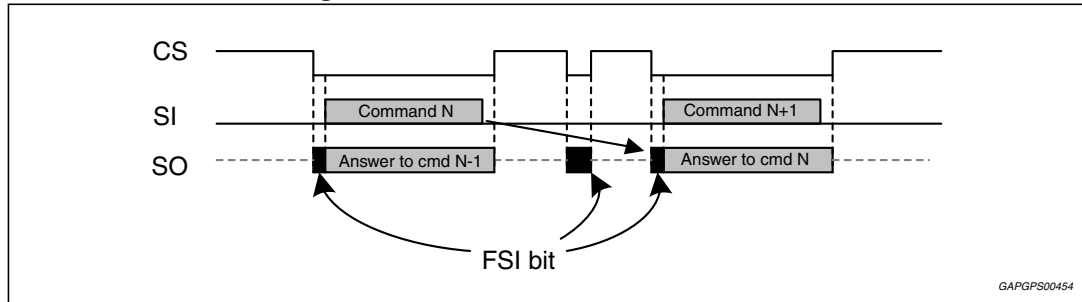
| Bit | Name | Description | Status after reset | Bit state | DR impact | H-bridge status |
|--------|----------|-----------------------------------|--------------------|-------------|-----------|-----------------|
| 0-LSB | OL_OFF | Open Load in OFF condition | 0 | Latched | — | — |
| 1 | OL_ON | Open Load in ON condition | 0 | Latched | — | — |
| 2 | VS_UV | Vs undervoltage | 0 | Not latched | — | Hi-Z if "1" |
| 3 | VDD_OV | Vdd overvoltage | 0 | Latched | X | Hi-Z if "1" |
| 4 | ILIM | Current Limitation reached | 0 | Latched | — | — |
| 5 | TWARN | Temperature warning | 0 | Latched | — | — |
| 6 | TSD | Over-temperature Shutdown | 0 | Latched | X | Hi-Z if "1" |
| 7 | ACT | Bridge enable | 1 | Not latched | — | Hi-Z if "0" |
| 8 | OC_LS1 | Over-Current on Low Side 1 | 0 | Latched | X | Hi-Z if "1" |
| 9 | OC_LS2 | Over-Current on Low Side 2 | 0 | Latched | X | Hi-Z if "1" |
| 10 | OC_HS1 | Over-Current on High Side 1 | 0 | Latched | X | Hi-Z if "1" |
| 11 | OC_HS2 | Over-Current on High Side 2 | 0 | Latched | X | Hi-Z if "1" |
| 12 | Null | Not Used | — | — | — | — |
| 13 | Null | Not Used | — | — | — | — |
| 14 | SGND_OFF | Short to GND in OFF condition | 0 | Latched | — | — |
| 15-MSB | SBAT_OFF | Short to Battery in OFF condition | 0 | Latched | — | — |

3.5 SPI communication failure

In case of "no SCK edge" when CS = '0', the transfer is considered as valid: no error is returned to the μ C. The answer of last command is sent during next transfer.

When the number of SCK period is different from 0 or multiple of 16, next SPI answer is all zero.

Figure 8. SPI zero clock communication



3.6 5 V and 3.3 V output compatibility

In order to ensure a full compatibility with 5 V and 3.3 V MCU peripherals, the pin VDDIO is dedicated to supply the output buffer of SO. The overall current consumption on Vddio is "Ivddio". A parasitic current from the pin SO could flow through the pin VDDIO in case of over-voltage on SO pin vs. VDDIO pin.

4 Current regulation

To protect the actuator and limit power dissipation, a two-level chopper current limitation is integrated as shown in figure below. The current is measured by sense cells integrated in the low-side switches. As soon the upper current limit “IH” is reached, both low-side drivers are switched on to allow free-wheeling recirculation, until the lower current limit “IL” is reached. During the current regulation, all the slew rate controls are disabled in order to minimize the power dissipation. Four current limit levels can be set by the SPI control bits 0 and 1. In order to achieve very precise current threshold and ripple, an external resistance is required (1 % accuracy on all temp range/lifetime) to generate a current reference. Detailed values for current thresholds and ripple are reported in [Table 6](#).

Figure 9. Current limitation

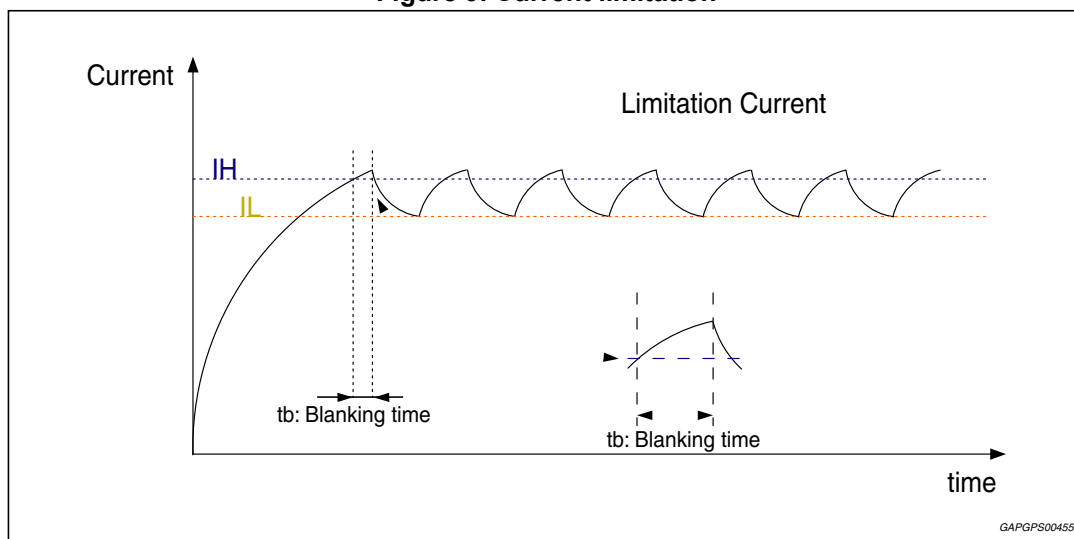


Table 6. Current limitation programmability

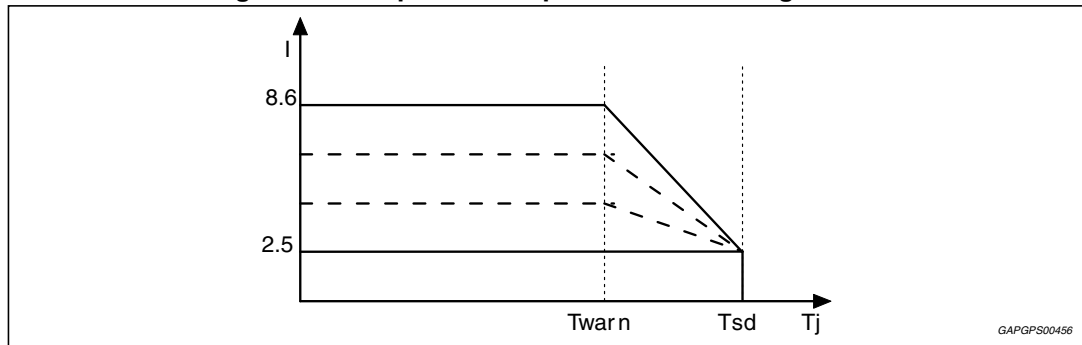
| CL_2 | CL_1 | Current limit (typical values) |
|------|------|--------------------------------|
| 0 | 0 | 2.5 A |
| 0 | 1 | 4 A |
| 1 | 0 | 6.6 A (default value) |
| 1 | 1 | 8.6 A |

4.1 Temperature-dependent current regulation

In order to reduce power dissipation and thus the junction temperature, above a temperature **Twarn** = 160 °C, current regulation high limit linearly decreases with temperature, to reach about 2.5 A at **Tsd** = 175 °C (shutdown temperature).

When this thermal threshold is reached during a current limitation phase, the information is stored and latched in a coding of bits called "**Twarn**". This bit can be reset only if the settings conditions ($T_j > T_{warn}$ and $I_{LIM} = 0$) are not present anymore. This feature is mainly used to reduce the power dissipation and thus the junction temperature.

Figure 10. Temperature dependent current regulation

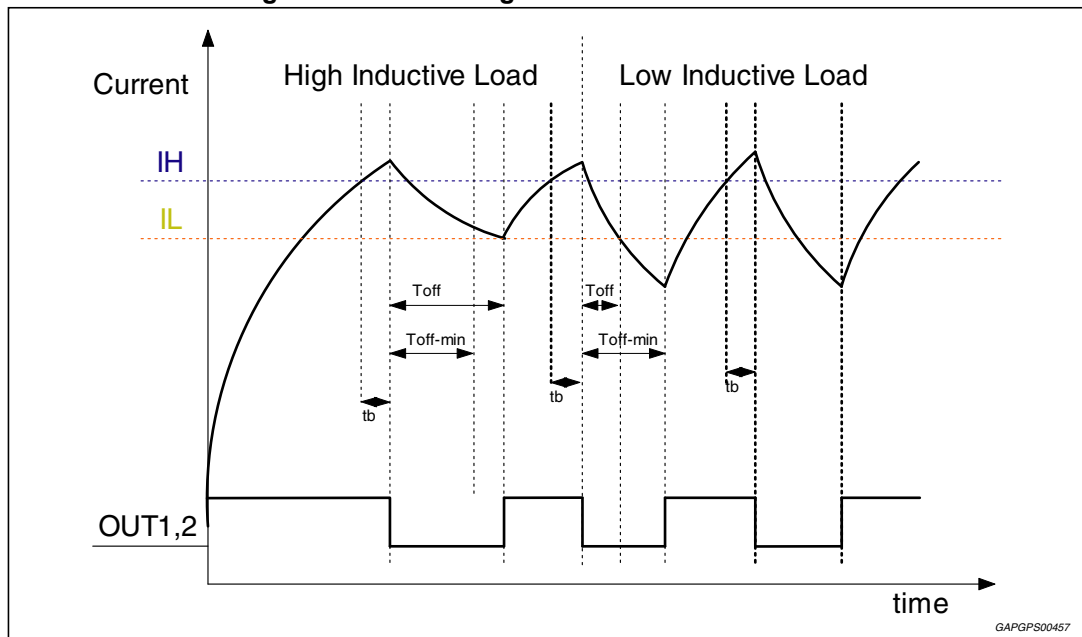


4.2 Current regulation with low-inductive loads

Each time output stages are turned off, an internal timing starts for duration **Toff-min**. Whenever turn-on is reached in a time **Toff** that is shorter than **Toff-min**, output stages are kept OFF, until **Toff-min** is reached.

In such case the ripple control could be not so precise as specified.

Figure 11. Current regulation with different loads



4.3 Slew rate control in case of current limitation on low-side

The slew rate control can be done on voltage and current or only on voltage. This can be selected by SPI through the bit **ISR_DIS**.

The slew rate of each high-side power transistor of the bridge is controlled either during turn-on and turn-off (current AND voltage slew rate). The same setting is applied for both switching. Moreover, this slew rate is configurable by SPI in order to get the best trade-off between conducted/radiated EMI and power dissipation during switching. The slew rate

selection can be done "on the fly" by SPI. The corresponding bits are called "VSR" and "ISR". No external component is needed to select the slew rate range. Only the power transistors not used for freewheeling can be adjusted, the two others can be controlled with a preset slew rate.

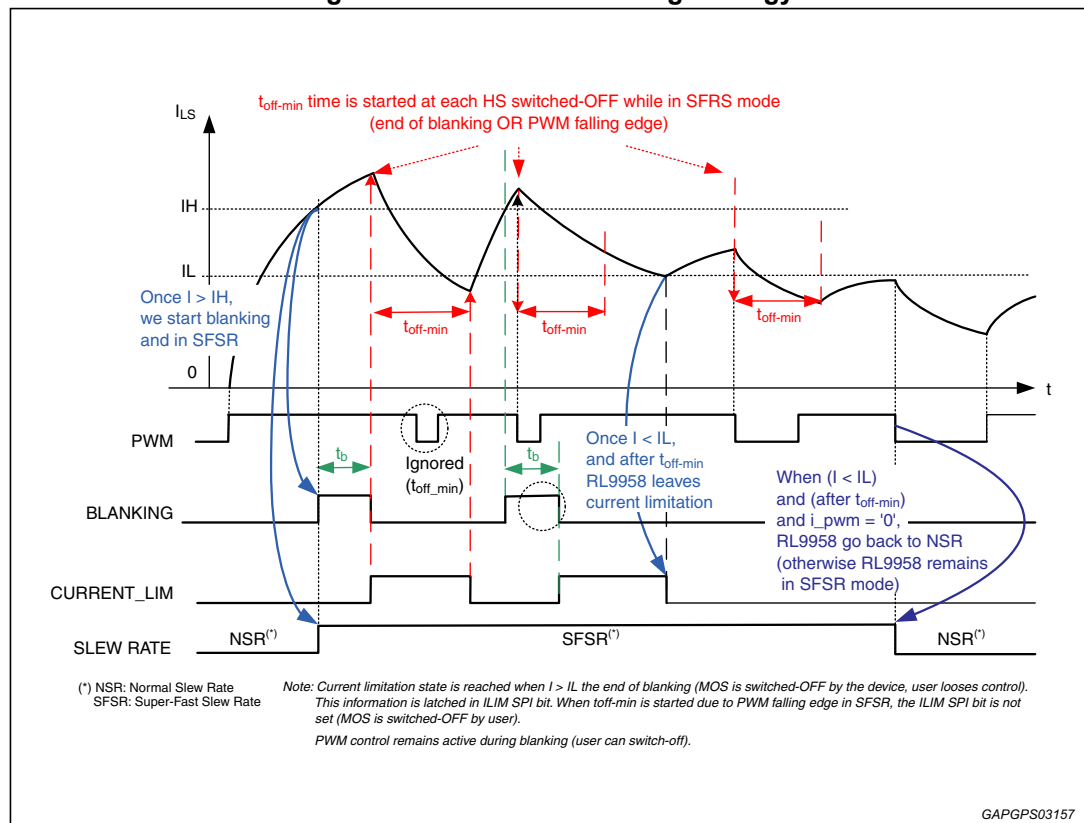
The couples of value defined to fulfill most of the application requirements are described in the table below. The required accuracy is $\pm 50\%$ for an output current from 1A to 8A and with output voltage up to 19 V. The overall delay implemented between high-side and low-side transistor switching must be adjusted automatically to avoid any cross-conduction through one half-bridge in all conditions.

Table 7. Slew rate control on low side MOS

| Range | VSR | ISR | dV/dt (V/ μ s) | dI/dt (A/ μ s) |
|-------------------|----------------|-----|--------------------|--------------------|
| 1 (default value) | 0 | 0 | 4 | 3 |
| 2 | 0 | 1 | 4 | 0.3 |
| 3 | 1 | 0 | 2 | 3 |
| 4 | 1 | 1 | 2 | 0.3 |
| No SR control | Not selectable | | 14 | 14 |

In case of current limitation and any detection that put the bridge in tri-state, the slew rate is not related anymore to the preset bits "VSR"; "ISR" but to a dedicated faster slew rate control named "SUPER FAST" mode. The automatic change from SPI selectable to SUPER FAST slew rate is described hereafter.

Figure 12. Slew rate switching strategy



5 Diagnostics and protections

A detailed diagnostic of the H-bridge is available through SPI communication. The 16 bits diagnostic word is sent back to the MCU in return of a command word. The diagnostic word is used to report two kinds of information:

- H-Bridge failures:
 - Over-current on each transistor in on-state,
 - Vps under-voltage,
 - Vdd over-voltage,
 - Over-temperature,
 - Open-load in on-state,
 - Off-state diagnostic.
- H-bridge functional status:
 - Current limitation condition,
 - Current limitation decreasing condition,
 - Disable / Enable status.

5.1 Diagnosis reset strategy

5.1.1 Reset requests

Except "ACT" and "VS_UV" bits, all the others are latched and can only be released by:

- Transition from "Disable" to "Enable" on DI / EN pins,
- Diagnostic register read by SPI (see details on each failure release) depending on bit "DR",
- Power-On-Reset condition.

When the diagnostic register is reset, the bridge is switched back to normal mode driven by DIR and PWM. All the settings are kept as before the failure. In case of SPI read, no additional action on DI / EN is needed.

5.1.2 Diagnosis reset bit

In case of "DR" set to LOW (default value), all the bits of the diagnostic register can be reset by the three possibilities described in previous section.

In case of "DR" set to HIGH, the over-current, Vdd over-voltage and over-temperature diagnostic bits can NOT be reset by SPI read and therefore, the bridge is kept in tri-state until a transition from "Disable" to "Enable" on DI/EN pins or Power-on-Reset condition.

Table 8. Diagnosis reset strategy

| DR | Diagnosis reset strategy |
|----|--|
| 0 | All diagnostic bits reset at each SPI reading (Default) |
| 1 | Over current bits (8..11) + Temp. shutdown TSD bit (6) + Vdd over voltage bit (3) NOT reset by SPI |

5.2 Protection and on state diagnostics

RL9958 is protected against short circuits, overload and invalid supply voltage by the following measures.

5.2.1 Over-current on high-side - short to ground

The high-side switches are protected against a short of the output to ground by an over-current shutdown. If a high-side switch is turned on and the current rises above the short circuit detection current I_{oc} all output transistors are turned off after a filter time T_{oc_Is} and the error bits "overcurrent on high side 1 (2)", **OC_HS1 (OC_HS2)** are stored in the internal status register.

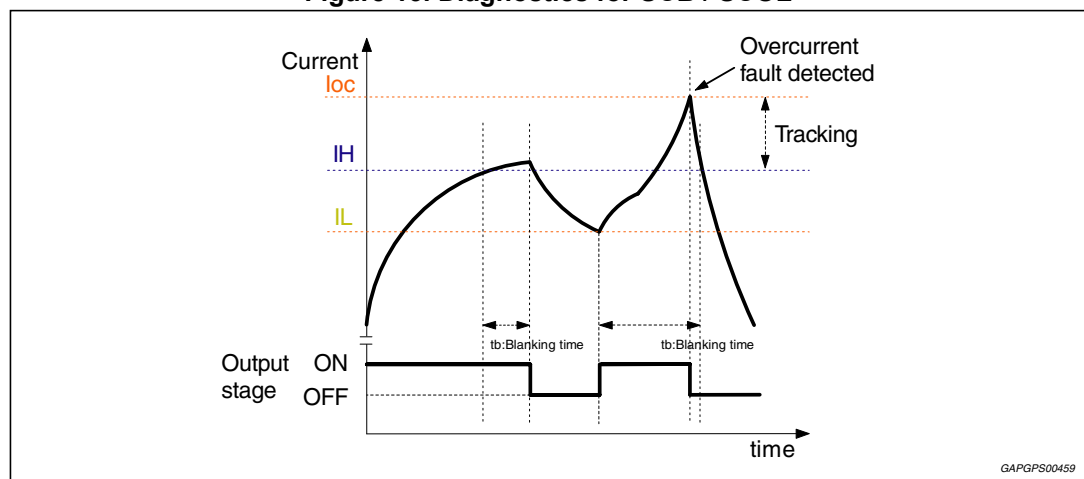
5.2.2 Over-current on low-side - short to Vs

Due to the chopper current regulation, the low-side switches are already protected against a short to the supply voltage. To be able to distinguish a short circuit from normal current limit operation, the current limitation is deactivated for the blanking time t_b after the current has exceeded the current limit threshold I_H . If the short circuit detection current I_{oc} is reached within this blanking time, a short circuit is detected. All output transistors are turned OFF and the according error bit "Over-Current on Low Side 1 (2)", **OC_LS1 (OC_LS2)** is set.

5.2.3 Short circuit over-load

If, during the Blanking time (t_b) of the current regulation mode, the current reaches the I_{oc} threshold; after a filtering time, the output MOS are switched OFF and the "Short circuit over load" can be checked by the reading of the overcurrent bits of the DIA_REG (please refer to [Table 5](#) bit 8, 9,10 and 11).

Figure 13. Diagnostics for SCB / SCOL

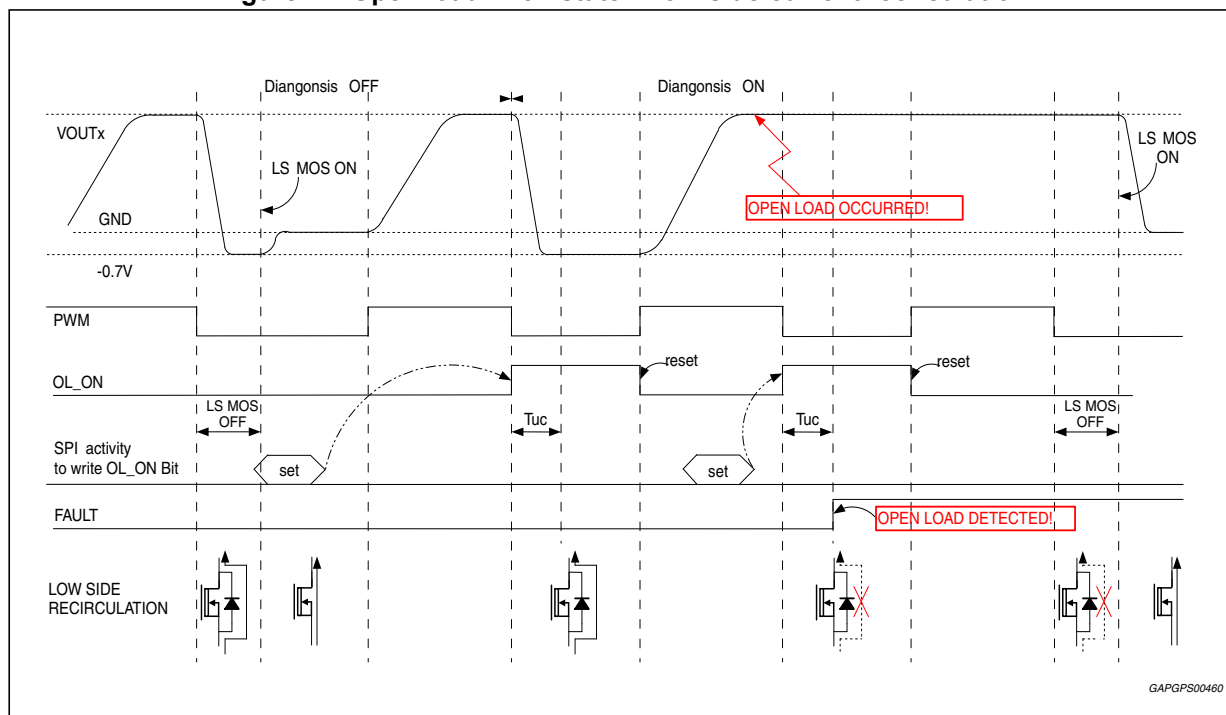


5.2.4 Open load in on state

To perform the Open Load diagnosis in ON state, the flag **OL_ON** has to be set high through SPI. After every open load diagnosis in ON state, the **OL_ON** flag is resetted, to perform a new open load diagnosis in ON state the **OL_ON** flag has to be set again.

This disable the turning on of the low-side drivers during current recirculation. The current flows through the body diode of the low-side MOS for a fixed time. At the end of this fixed time the Vout voltage is sampled and the possible open load condition detected (see Figure 14).

Figure 14. Open load in on state - Low-side current recirculation



5.2.5 Over-temperature

When **T_{warn}** is reached, thermal current reduction is activated, and the information is stored and latched. When **T_{sd}** is reached, the "TSD" bit is set and all output transistors are put in tri-state conditions as long as a reset is applied.

Table 9. Over-temperature

| TSD | Comments | Bridge state | FSI |
|-------------|----------------------|--------------|-----|
| 1 | T _j > TSD | Tri-state- | 1 |
| 0 (default) | T _j < TSD | - | 0 |

5.2.6 Vs under-voltage shutdown

If the supply-voltage at the V_S pins falls below the under-voltage detection threshold **V_{s_uv_off}**, the outputs are set to tri-state and the error bit "Undervoltage at V_S" is set. A filtering time "**T_{uv_Vs}**" is implemented to avoid unwanted detection due to parasitic glitches. The information is transferred into the SPI register in a bit called "**VS_UV**". This bit is NOT latched. As soon as the voltage rises again above the V_s under-voltage threshold (hysteresis implemented), the bridge is switched back to normal mode driven by DIR and PWM. All the settings are kept as before the under-voltage event.

Figure 15. Battery voltage monitoring

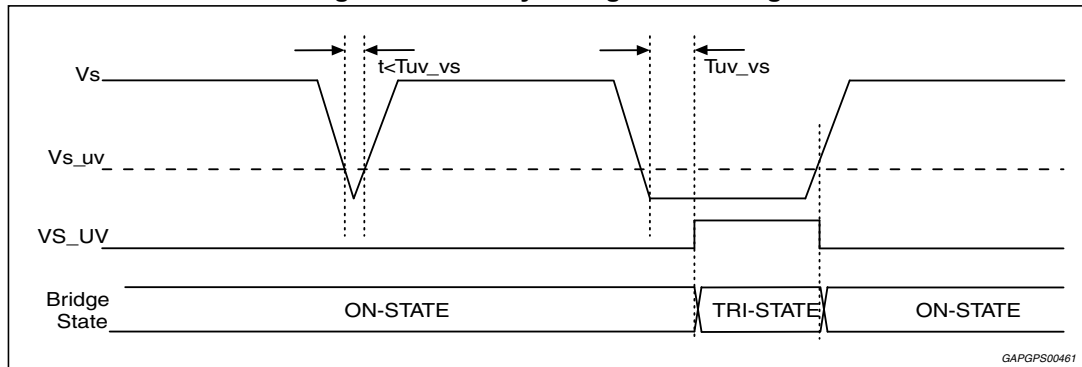


Table 10. Vs under-voltage

| VS_UV | Comments | Bridge state | FSI |
|-------------|------------------------|--------------|-----------------|
| 1 | $V_s < V_{s_uv_off}$ | Hi Z | 1 (not latched) |
| 0 (default) | $V_s > V_{s_uv_on}$ | - | 0 |

5.2.7 Vdd over-voltage detection

Although the Vdd input pin and all I/O's are able to withstand up to 19 V, an over-voltage circuitry is implemented to ensure that the bridge is kept in tri-state when the Vdd voltage is higher than the Vdd overvoltage threshold "**Vdd_ov_off**" for duration longer than "**Tov_Vdd**". The information is detected and stored into the SPI register in a bit called "**VDD_OV**". The bridge is kept in tri-state as long as an appropriate reset is not requested (see [Section 5.1](#)).

Table 11. Vdd over-voltage detection

| VDD_OV | Comments | Bridge state | FSI |
|-------------|----------------------------|--------------|-------------|
| 1 | $V_{dd} > V_{dd_ov_off}$ | Hi-Z | 1 (latched) |
| 0 (default) | $V_{dd} < V_{dd_ov_on}$ | - | 0 |

5.2.8 Vdd under-voltage detection

When the Vdd voltage falls below the under-voltage detection threshold "**Vdd_uv_off**" for duration longer than "**Tuv_vdd**", the bridge is switched to tri-state. In such a condition, the RL9958 is going in sleep mode. When the voltage increases above the threshold (hysteresis implemented), the RL9958 starts with all the settings reset to their default values (Power On Reset).

5.2.9 Output short protection

The RL9958 can sustain short on the outputs. In case of short to GND, short to battery or short between outputs the battery voltage cannot exceed 18 V. The connection of a 100 μ F plus a 1 μ F decoupling capacitors as close as possible to V_s pin and the GND connection of the slug or of the exposed pad is mandatory to improve the robustness.

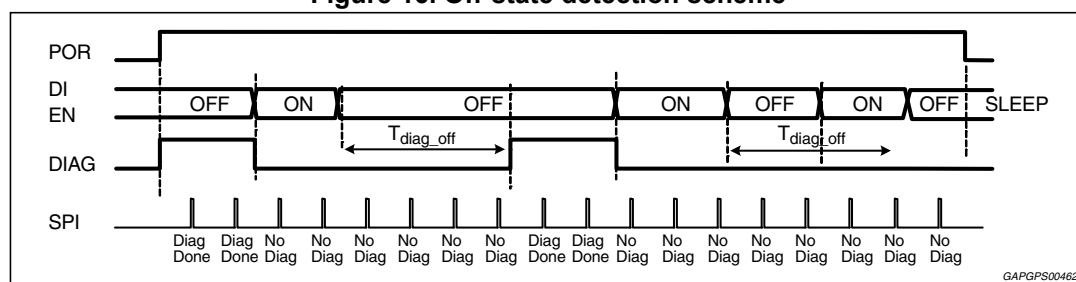
5.3 Off-state diagnosis

This diagnostic is performed in any off-state condition, just after ignition key-on or during an off-state phase occurring after an on-state phase of the bridge.

5.3.1 Off-state detection scheme

In order to avoid any wrong diagnostic, a filtering time "Tdiag_off" is applied before performing the detection if the bridge was in on-state before. This filtering time is not applied in case of detection after key on.

Figure 16. Off-state detection scheme

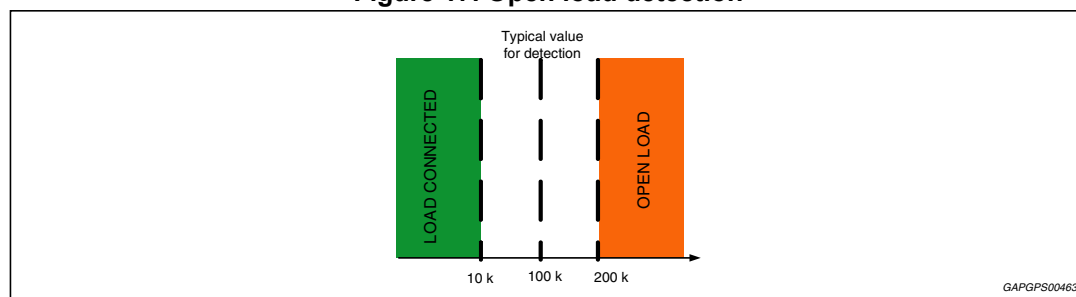


5.3.2 Open load detection

An equivalent resistor of 100 kΩ (typ.) is targeted for open-load detection.

In order to avoid any unwanted supply of the bridge through the high-side transistor body diode during off-state measurement, the current source is connected only if Vs is higher than the Vs under-voltage threshold.

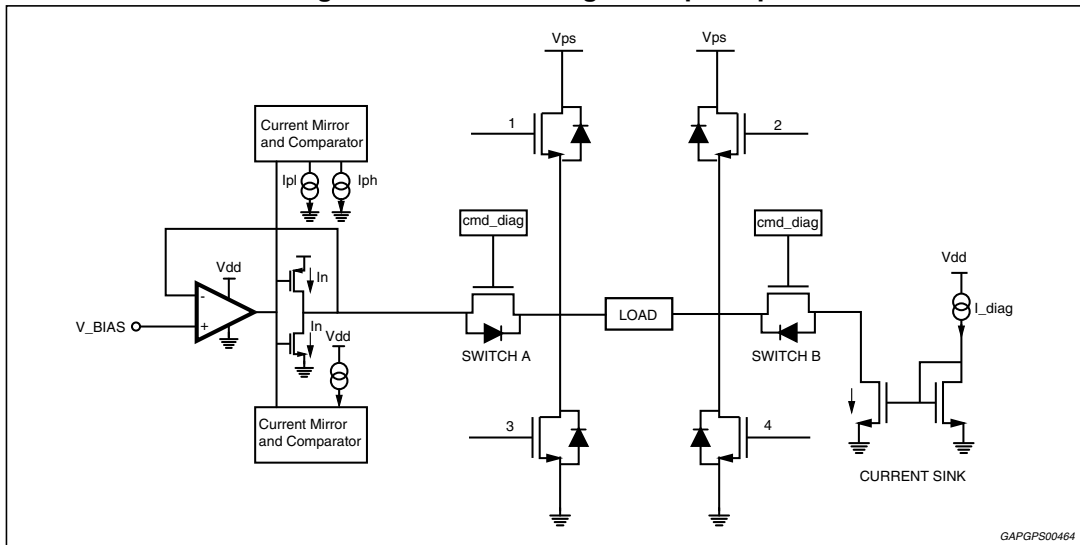
Figure 17. Open load detection



The diagnostic is based on a closed loop voltage control on OUT1 and associated current measurement.

A voltage amplifier forces a constant voltage on OUT1 through two current sources (high-side source and low-side current sink). The OUT2 is pulled-down through a constant current sink. Based on the current flowing out of the amplifier ($I_p - I_n$) compared to several current thresholds, open-load as well as short-circuit to ground and battery can be detected.

Figure 18. Off-state diagnostic principle



5.4 H-Bridge functional status

Three bits in the diagnosis register are used to give a feedback about the state of the H-Bridge. Status are Current Limitation (bit 4 "C_LIM"), Temperature Warning (bit 5 "T_WRN") and Bridge Enable Status (bit 7 "ACT"). Those bits do not report a failure but only a functional state of the H-bridge that could be useful to change the control strategy mainly in term of power dissipation.

6 Electrical specifications

6.1 Absolute maximum ratings

The component must withstand the overall following stimulus without any damage or latch-up. Beyond these values, damage to the component may occur.

Table 12. Absolute maximum ratings

| Symbol | Parameter | Test condition | Min. | Max. | Unit |
|----------------------------|----------------------|---|----------|----------------|------|
| V_{ps} | Supply voltage | Continuous Transient (0.5 s; $I \leq 10$ A) | -1 -2 | 40 40 | V |
| V_{dd} | Logic supply voltage | $0\text{ V} < V_{ps} < 40\text{ V}$ | -0.3 | 19 | V |
| V_{ddio} | SDO supply voltage | $0\text{ V} < V_{ps} < 40\text{ V}$ | -0.3 | 19 | V |
| V_i | Logic input voltage | $0\text{ V} < V_{ps} < 40\text{ V}$ $0\text{ V} < V_{dd} < 19\text{ V}$ | -0.3 | 19 | V |
| V_o | Logic output voltage | $0\text{ V} < V_{ps} < 40\text{ V}$ $0\text{ V} < V_{dd} < 18.7\text{V}$ | -0.3 | $V_{ddio}+0.3$ | V |
| Output pins (OUTx, VPS) | ESD Compliance | EIA/JESD22-A114-B | ± 4 | - | kV |
| Input pins | | | ± 2 | - | |
| - | ISO 7637 pulses | Cf. standards | - | - | - |
| - | Latch-up immunity | Jedec standard | -100 | +100 | mA |

Note: In case of load dump condition, status of device outputs is kept unchanged.

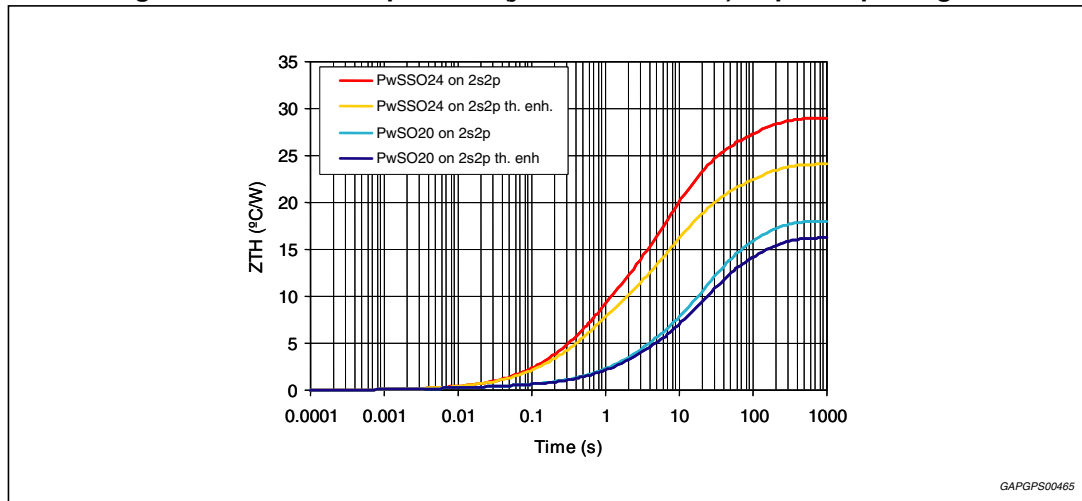
6.2 Thermal data

Table 13. Thermal data

| Symbol | Parameter | Test condition | Min. | Max. | Unit |
|----------------|--|-------------------------------------|------|------|------|
| T_j | Junction temperature | Failure condition | -40 | OTsd | °C |
| | | Lifetime | -40 | 150 | |
| T_{stg} | Storage temperature | - | -55 | 150 | °C |
| T_{amb} | Ambient temperature | $0\text{ V} < V_{ps} < 40\text{ V}$ | -40 | 125 | °C |
| $R_{thj-case}$ | Thermal resistance junction to case ⁽¹⁾ | - | - | 1 | °C/W |

1. Guaranteed by design and package characterization.

Figure 19. Thermal impedance (junction-ambient) of power packages



6.3 Range of functionality

Within the range of functionality, all RL9958 functionalities have to be guaranteed. All voltages refers to GND. Currents are positive into and negative out of the specified pin.

Table 14. Range of functionality

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|--------------|--|--|------------|------|----------------------|------------|
| FR1 | V_{ps} | Supply voltage | - | Vps_uv_off | 14 | 28 ⁽¹⁾ | V |
| FR2 | dV_{ps}/dt | Supply voltage slew rate | - | -20 | - | 20 | V/ μ s |
| FR3 | V_{dd} | Logic supply voltage | - | Vdd_uv_off | 5 | Vdd_ov_off | V |
| FR4 | dV_{dd}/dt | Logic supply voltage slew rate | - | - | - | 0.025 ⁽²⁾ | V/ μ s |
| FR5 | V_i | Logic input voltage (SDI, SCLK, NCS, DI, EN, DIR, PWM) | See also Table 12: Absolute maximum ratings. | -0.3 | - | Vdd_ov_off | V |
| FR6 | V_{ddio} | SDO output voltage | - | 3 | - | 5.5 | V |
| FR7 | f_{spi} | SPI clock frequency | - | - | - | 5 | MHz |

1. In load dump conditions V_{ps} ranges between 28V and 40V. During load dump, status of device outputs is kept unchanged,
2. To VDD pin are connected 10 μ F and 10nF (close to the pin) capacitors.

6.4 Electrical characteristics

$T_{\text{case}} = -40\text{ °C}$ to 125 °C unless otherwise specified,

$V_{\text{dd}} = 4.5\text{ V}$ to 5.5 V unless otherwise specified

$V_{\text{ps}} = 4\text{ V}$ to 28 V unless otherwise specified

All voltages refer to GND. Currents are positive into and negative out of the specified pin.

6.4.1 Device supply

Table 15. Device supply

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|------------------|---------------------------|--|------|------|------|---------------|
| 1.1 | I_{ps} | Power supply current | $V_{\text{dd}} < 0.7\text{ V}$; $V_{\text{ps}} = 16\text{ V}$ from -40 °C to 25 °C | - | - | 20 | μA |
| | | | $V_{\text{dd}} < 0.7\text{ V}$; $V_{\text{ps}} = 16\text{ V}$ at 125 °C | - | - | 35 | μA |
| | | | $F_{\text{pwm}} = 0$, $I_{\text{out}} = 0$ | - | - | 20 | mA |
| 1.2 | I_{out} | Leakage current on output | Bridge in tri-state | - | - | 100 | μA |
| 1.3 | I_{cc} | Logic-supply current | $V_{\text{dd}} > V_{\text{dd_uv_on}}$ $F_{\text{PWM}} = 0$ | - | - | 5 | mA |
| | | | $F_{\text{PWM}} = 20\text{ kHz}$ (Average value) | - | - | 5 | mA |

6.4.2 Device supply monitoring

Table 16. Device supply monitoring

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|---------------------------|--|----------------------------|------|------|------|---------------|
| 2.1 | $V_{\text{ps_uv_off}}$ | V_{ps} under-voltage threshold | V_{ps} decreasing | - | - | 4 | V |
| 2.2 | $V_{\text{ps_uv_on}}$ | V_{ps} under-voltage threshold | V_{ps} increasing | - | - | 4.5 | V |
| 2.3 | $V_{\text{ps_uv_hyst}}$ | V_{ps} under-voltage hysteresis | - | 0.1 | - | - | V |
| 2.4 | $T_{\text{uv_vps}}$ | V_{ps} under-voltage filtering time | V_{ps} decreasing | 1 | - | 3 | μs |
| 2.5 | $V_{\text{dd_uv_off}}$ | V_{dd} under-voltage threshold | V_{dd} decreasing | 3 | - | 3.7 | V |
| 2.6 | $V_{\text{dd_uv_on}}$ | V_{dd} under-voltage threshold | V_{dd} increasing | 3.3 | - | 4 | V |
| 2.7 | $V_{\text{dd_uv_hyst}}$ | V_{dd} under-voltage hysteresis | - | 0.1 | - | - | V |
| 2.8 | $T_{\text{uv_Vdd}}$ | V_{dd} under-voltage filtering time | V_{dd} decreasing | 1 | - | 4 | μs |
| 2.9 | $V_{\text{dd_ov_off}}$ | V_{dd} over-voltage threshold | V_{dd} increasing | 5.8 | - | 6.8 | V |
| 2.10 | $V_{\text{dd_ov_on}}$ | V_{dd} over-voltage threshold | V_{dd} decreasing | 5.5 | - | 6.5 | V |
| 2.11 | $V_{\text{dd_ov_hyst}}$ | V_{dd} over-voltage hysteresis | - | 0.1 | - | - | V |
| 2.12 | $T_{\text{ov_Vdd}}$ | V_{dd} over-voltage filtering time | V_{dd} increasing | 60 | 100 | 140 | μs |

6.4.3 SPI

Table 17. SPI

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|------------------|--|--|------------------|------|------|---------------|
| 3.1 | f_{spi} | Clock frequency (50 % duty cycle) | - | - | - | 5 | MHz |
| 3.2 | T_{sdo_trans} | SDO transition speed, 20-80 % | $V_{sdo} = 5V, C_{load} = 50 \text{ pF}^{(1)}$ | 5 | - | 30 | ns |
| | | | $V_{sdo} = 5V, C_{load} = 150 \text{ pF}$ | 5 | - | 50 | ns |
| 3.3 | T_{clh} | Minimum time SCLK = HIGH | - | 75 | - | - | ns |
| 3.4 | T_{cll} | Minimum time SCLK = LOW | - | 75 | - | - | ns |
| 3.5 | T_{pold} | Propagation delay (SCLK to data at 10% of SDO rising edge) | - | - | - | 40 | ns |
| 3.6 | T_{csdv} | NCS = LOW to data at SDO active | - | - | - | 85 | ns |
| 3.7 | T_{sclch} | SCLK low before NCS low (setup time SCLK to NCS change H/L) | - | 75 | - | - | ns |
| 3.8 | T_{hclcl} | SCLK change L/H after NCS = low | - | 75 | - | - | ns |
| 3.9 | T_{sclsd} | SDI input setup time (SCLK change H/L after SDI data valid) | - | 40 | - | - | ns |
| 3.10 | T_{hclsd} | SDI input hold time (SDI data hold after SCLK change H/L) | - | 40 | - | - | ns |
| 3.11 | T_{sclcl} | SCLK low before NCS high | - | 100 | - | - | ns |
| 3.12 | T_{hclch} | SCLK high after NCS high | - | 100 | - | - | ns |
| 3.13 | T_{pchs} | NCS L/H to SDO @ high impedance | - | - | - | 75 | ns |
| 3.14 | T_{onncs} | NCS min. high time | - | 300 | - | - | ns |
| 3.15 | - | Capacitance at SDI, SCLK; NCS | - | - | - | 14 | pF |
| | - | Capacitance at SDO | - | - | - | 19 | pF |
| 3.16 | T_{fncs} | NCS Filter time will be ignored) Guaranteed by design (Pulses = T_{fncs}) | Guaranteed by design | 10 | - | 40 | ns |
| 3.17 | V_{ddio} | Supply voltage for SDO output buffer | - | 3 | - | 5.5 | V |
| 3.18 | sdo_H | High output level on SDO | $I_{sdo} = 1.5 \text{ mA}$ | $V_{ddio} - 0.4$ | - | - | V |
| 3.19 | sdo_L | Low output level on SDO | $I_{sdo} = 2 \text{ mA}$ | - | - | 0.4 | V |
| 3.20 | I_{sdo} | Tri state leakage current | NCS = HIGH $V_{DDIO} = 5 \text{ V}$ | -5 | - | 5 | μA |

1. Not tested – guaranteed by $C_{load} = 150 \text{ pF}$ measurement

6.4.4 Digital inputs: TTL // 3.3V / 5V CMOS compatible

Table 18. Digital inputs: TTL // 3.3V / 5V CMOS compatible

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|---------------|---|--|------|------|--------------|---------------|
| 4.1 | V_{ih} | Input voltage HIGH | - | 2 | - | $V_{dd}+0.3$ | V |
| 4.2 | V_{il} | Input voltage LOW | - | -0.3 | - | 0.8 | V |
| 4.3 | | Hysteresis of input voltage | - | 200 | - | - | mV |
| 4.4 | I_{inl} | Input current source for: DI / NCS / SCLK / SDI | $V_{in} = 0\text{ V}$ | -100 | - | -30 | μA |
| | | | $V_{in} = 5\text{ V}$ No back supply allowed | - | - | 5 | |
| 4.5 | I_{inh} | Input current sink for: EN / DIR / PWM | $V_{in} = 5\text{ V}$ | 30 | - | 100 | μA |
| | | | $V_{in} = 0\text{ V}$ | -5 | - | - | |
| 4.6 | $V_{r_{ext}}$ | External resistor | - | - | 1.24 | - | V |
| | R_{ext} | | - | - | 10 | - | k Ω |
| | | | Overall tolerance can be taken as 3.5 % | - | 1 | - | % |

6.4.5 Bridge output drivers

Table 19. Bridge output drivers

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|---------------|--|--|------|------|------|------------|
| 5.1 | R_{dson_h} | High-side transistor R_{dson} | $T_j = 150\text{ }^\circ\text{C}$, $I_{out} = 3\text{ A}$ $4\text{ V} < V_{ps} < 5\text{ V}$ | - | - | 300 | m Ω |
| | | | $T_j = 150\text{ }^\circ\text{C}$, $I_{out} = 3\text{ A}$ $V_{ps} > 5\text{ V}$ | - | - | 150 | |
| 5.2 | R_{dson_l} | Low-side transistor R_{dson} | $T_j = 150\text{ }^\circ\text{C}$, $I_{out} = 3\text{ A}$ $4\text{ V} < V_{ps} < 5\text{ V}$ | - | - | 300 | m Ω |
| | | | $T_j = 150\text{ }^\circ\text{C}$, $I_{out} = 3\text{ A}$ $V_{ps} > 5\text{ V}$ | - | - | 150 | |
| 5.3 | V_{bd_h} | Body diode forward voltage drop high-side transistor | $I_{diode} = 3\text{ A}$ | - | 1.2 | 2 | V |
| 5.4 | V_{bd_l} | Body diode forward voltage drop low-side transistor | $I_{diode} = 3\text{ A}$ | - | 1.2 | 2 | V |

6.4.6 Over-temperature monitoring

Table 20. Over-temperature monitoring

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|------------------|---------------------------------|---------------------------------|------|------|------|------|
| 6.1 | OTwarn | Over-temperature warning | - | 150 | - | 170 | °C |
| 6.2 | OTsd | Over-temperature shut-down | - | 170 | - | 200 | °C |
| 6.3 | OThyst | Over-temperature hysteresis | - | 10 | - | - | °C |
| 6.4 | T _{TSD} | Over-temperature filtering time | Guaranteed by clock measurement | - | 36 | - | µs |

6.4.7 Current limitation and over-current detection

Table 21. Current limitation and over-current detection

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|---------------------|--|--|---|---|---|------|
| 7.1 | I _{lim_H} | Current limitation high threshold | CL1:0 = 00; -40 °C ≤ T _j ≤ 150 °C | 2 | 2.5 | 3.1 | A |
| | | | CL1:0 = 01; -40 °C ≤ T _j ≤ 150 °C | 3.5 | 4 | 4.85 | |
| | | | CL1:0 = 10; -40 °C ≤ T _j < 25 °C | 5.5 | 6.75 | 8 | |
| | | | CL1:0 = 10; 25 °C ≤ T _j ≤ 150 °C | 5.5 | 6.6 | 7.7 | |
| | | | CL1:0 = 11; -40 °C ≤ T _j < 25 °C | 7.8 | 9.1 | 10.4 | |
| | | | CL1:0 = 11; 25 °C ≤ T _j ≤ 150 °C | 7.6 | 8.6 | 9.6 | |
| | | | CL1:0 = XX, T _j = OTsd | 2 | 2.5 | 3 | |
| 7.2 | I _{lim_L} | Current limitation low threshold | CL1:0 = 0X; -40 °C ≤ T _j ≤ 150 °C | I _{lim_H} -0.2 | I _{lim_H} ⁻ 0.5 | I _{lim_H} ⁻ 0.8 | A |
| | | | CL1:0 = 10; -40 °C ≤ T _j < 25 °C | I _{lim_H} ⁻ 0.35 | I _{lim_H} ⁻ 0.65 | I _{lim_H} ⁻ 0.95 | |
| | | | CL1:0 = 10; 25 °C ≤ T _j ≤ 150 °C | I _{lim_H} ⁻ 0.35 | I _{lim_H} ⁻ 0.55 | I _{lim_H} ⁻ 0.85 | |
| | | | CL1:0 = 11; -40 °C ≤ T _j < 25 °C | I _{lim_H} -0.4 | I _{lim_H} ⁻ 0.7 | I _{lim_H} -1 | |
| | | | CL1:0 = 11; 25 °C ≤ T _j ≤ 150 °C | I _{lim_H} -0.4 | I _{lim_H} ⁻ 0.55 | I _{lim_H} ⁻ 0.95 | |
| 7.3 | T _{limh} | High current limitation threshold filtering time | can be included in T _{blank} | 0.1 | - | 1 | µs |
| 7.4 | T _{liml} | Low current limitation threshold filtering time | - | 1 | - | 3 | µs |
| 7.5 | T _{offmin} | Current limitation delay time | - | 30 | - | 45 | µs |
| 7.6 | T _b | Blanking time | - | 4.9 | - | 8.7 | µs |

Table 21. Current limitation and over-current detection (continued)

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|------------------|--|--|------------------|------|------|---------------|
| 7.7 | loc_ls loc-hs | Low-side over-current threshold | CL1:0 = 0X; $-40\text{ °C} \leq T_j \leq 150\text{ °C}$ | 5.5 | 7.7 | 11 | A |
| | | | CL1:0 = 1X; $-40\text{ °C} \leq T_j < 25\text{ °C}$ | 9.3 | 12 | 16.5 | |
| | | | CL1:0 = 1X; $25\text{ °C} \leq T_j \leq 150\text{ °C}$ | 9.3 | 11.5 | 14 | |
| | Tracking | High-side over-current threshold | CL1:0 = 0X; CL1:0 = 10; $-40\text{ °C} \leq T_j \leq 150\text{ °C}$ | $I_{lim_h}+2$ | - | - | |
| | | | CL1:0 = 11; $-40\text{ °C} \leq T_j \leq 150\text{ °C}$ | $I_{lim_h}+1.3$ | - | - | |
| 7.8 | Toc_ls Toc_hs | Low-side & high-side over-current detection filtering time | - | 0.8 | - | 2.5 | μs |

6.4.8 Diagnostic of open-load in on-state

Table 22. Diagnostic of open-load in on-state

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|----------|--------------------------------|--|------|------|------|---------------|
| 8.1 | Is_OL-on | Current source | $T_j = -40\text{ °C}$ (go-no-go functional test) | 50 | - | 120 | μA |
| | | | $T_j = 25\text{ °C}$ to 150 °C (go-no-go functional test) | 50 | - | 100 | |
| 8.2 | Tmeas_on | Detection time (settling time) | - | - | 3 | 5 | μs |

6.4.9 Off-state diagnostic

Table 23. Off-state diagnostic

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|------|-------------------------|---|--|------|------|------|---------------|
| 9.1 | R _{OL} | Load detection threshold | | 10 | 60 | 200 | k Ω |
| 9.2 | Tdiag_off | Delay time before enabling off-state diagnostic structure | diag after on-state Guaranteed through SCAN | 100 | 125 | 150 | ms |
| 9.3 | T _{diag-off_1} | Off-state diag filtering time when OUT 1 and/or 2 decrease from V _{ps} | used each time OUT pins are released from V _{ps} (after release of SCB, after Tdiag_off) Guaranteed through SCAN | 2.4 | 3 | 3.6 | ms |
| 9.4 | T _{diag-off_2} | Off-state diagnostic filtering time on failure detection | One symmetric filter for each failure type (OL, SCG, SCB) Guaranteed through SCAN | 200 | 250 | 300 | μs |
| 9.5 | T _{clock} | Oscillator frequency | - | 4 | - | 6 | MHz |

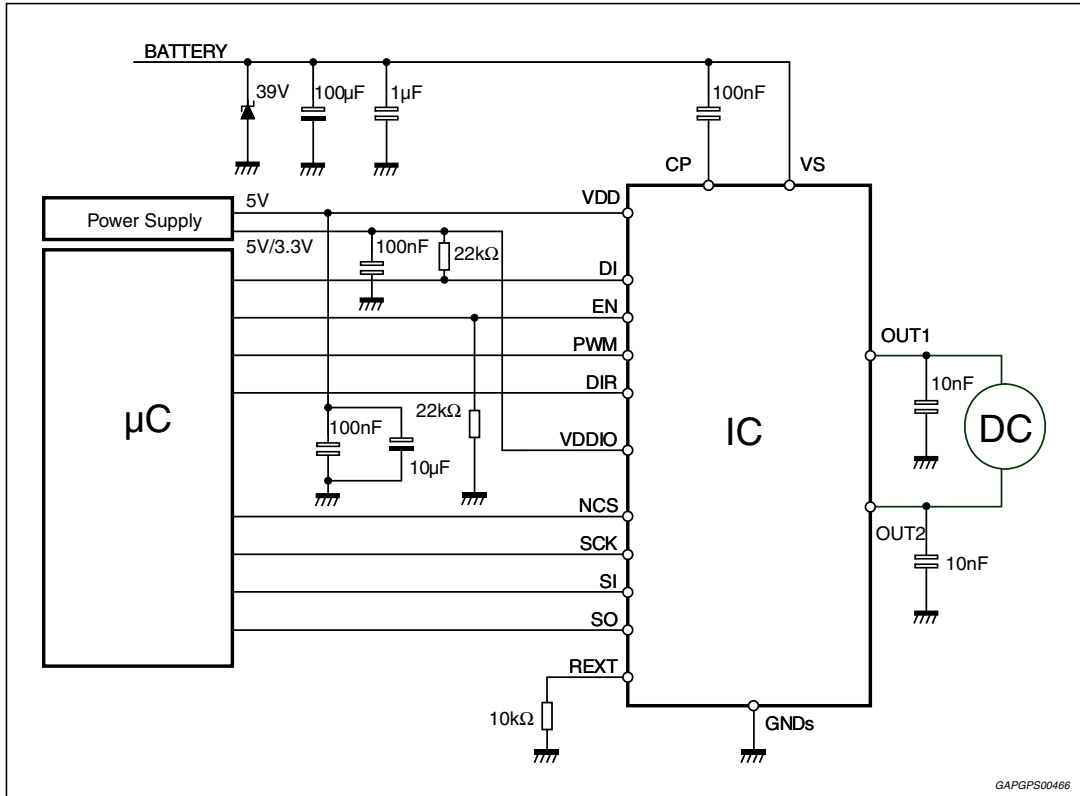
6.4.10 Timing characteristics

Table 24. Timing characteristics

| Pos. | Symbol | Parameter | Test condition | Min. | Typ. | Max. | Unit |
|-------|-----------------|--|--|------|------|------|------------|
| 10.1 | f_{pwm} | PWM frequency | - | - | - | 20 | kHz |
| 10.2 | T_{don} | Delay time for switch-on | $R_{load} @ I_{out} = 3 A$ PWM \rightarrow 90% V_{out} (or 10% I_{out}) | - | - | 10 | μs |
| | T_{doff} | Delay time for switch-off | $R_{load} @ I_{out} = 3 A$ PWM \rightarrow 10% V_{out} (or 90% I_{out}) | - | - | 10 | μs |
| | ΔT_d | Delay time: symmetry | PWM accuracy = 1% @ 2kHz | - | - | 5 | μs |
| 10.3 | T_{d_dis} | Disable delay time | DI / EN \rightarrow 90% OUTx @ $I_{out} = 3 A$ | - | - | 6 | μs |
| 10.4 | T_{d_en} | Enable delay time | DI / EN \rightarrow 10% OUT | - | - | 6 | μs |
| 10.5 | T_{d_pow} | Power-on delay time | DIR= PWM=EN=1 / DI=0 no load / $V_{PS} =$ V_{dd} increasing $V_{ps} = V_{dd} \rightarrow$ 10% V_{out1} (= V_{ps}) | - | - | 200 | μs |
| 10.6 | T_{d_filter} | DI / EN digital filter time | - | 1 | - | 3 | μs |
| 10.7 | T_{rise_H} | Low-side transistor rise time | Non selectable by SPI | 0.04 | - | 0.2 | μs |
| 10.8 | T_{fall_H} | Low-side transistor fall time | Non selectable by SPI | 1 | - | 3 | μs |
| 10.9 | dV_{out}/dt | Voltage slew rate for high-side transistors (Measurement is performed between 30% and 70% of the slope) | super fast mode | 7 | 14 | 24 | V/ μs |
| | | | VSR = 0 | 2 | 4 | 6 | |
| | | | VSR = 1 | 1 | 2 | 3 | |
| 10.10 | dI_{out}/dt | Current slew rate for high-side transistors (Measurement is performed between 40% and 60% of the slope) | ISR=0 | 1.5 | 3 | 4.5 | A/ μs |
| | | | ISR=1 | 0.15 | 0.3 | 0.45 | |
| 10.11 | T_{diag} | Timing for reliable diagnostic | Guaranteed through SCAN pattern | 35 | - | 55 | μs |

7 Application circuit

Figure 20. Application circuit



1. The above application diagram shows all the suggested components for a proper device operation.

8 Order codes

Table 25. Ordering information

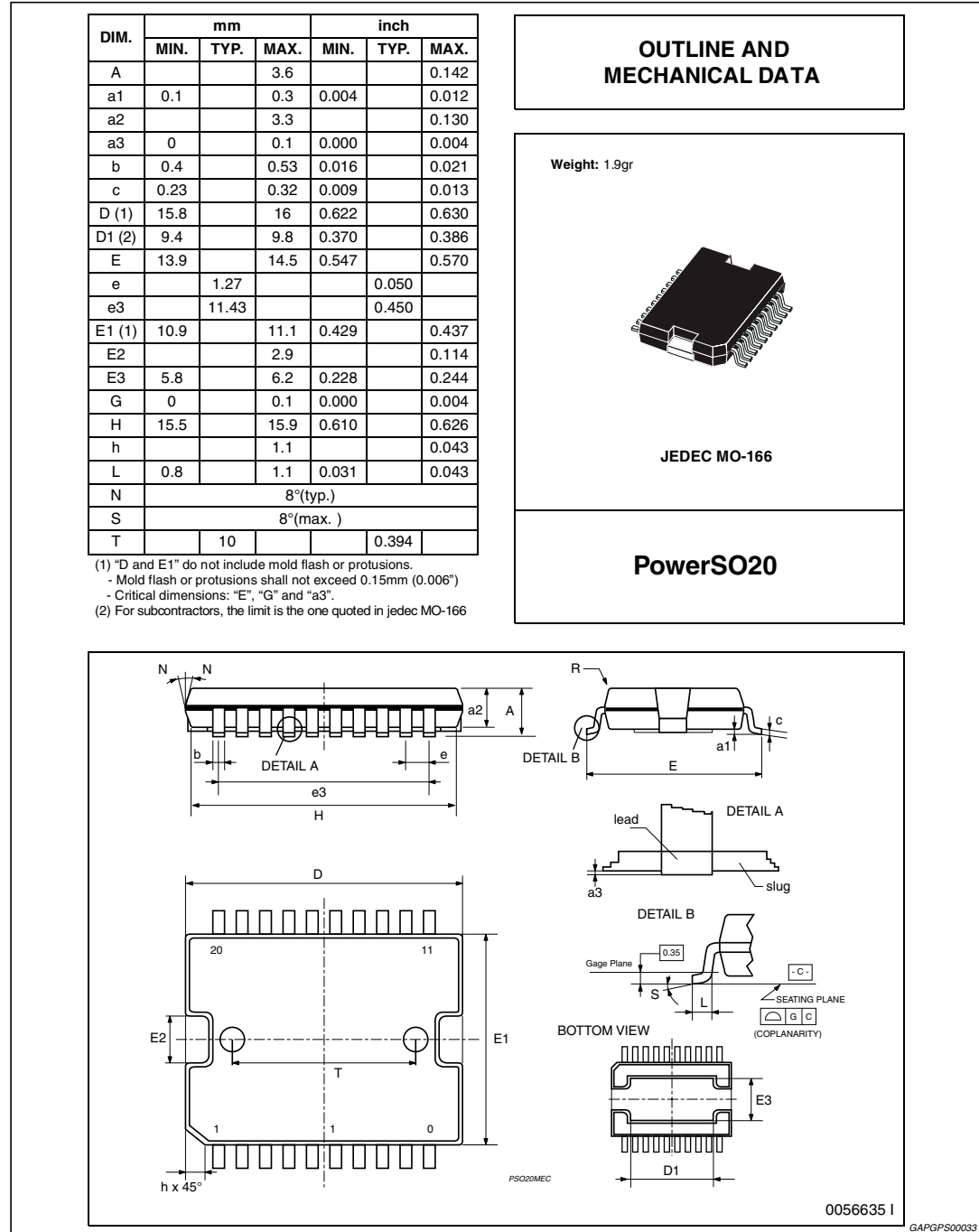
| Order code | Package | Packing |
|-------------------|----------------|----------------|
| RL9958 | PowerSO-20 | Tube |
| RL9958TR | | Tape & Reel |

9 Package information

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK® packages, depending on their level of environmental compliance. ECOPACK® specifications, grade definitions and product status are available at: www.st.com.

ECOPACK® is an ST trademark.

Figure 21. PowerSO-20 mechanical data and package dimensions



10 Revision history

Table 26. Document revision history

| Date | Revision | Changes |
|-------------|----------|------------------|
| 16-Sep-2014 | 1 | Initial release. |

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