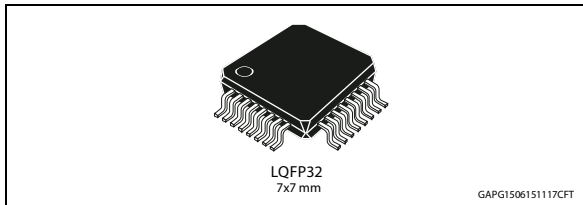


High efficiency constant current LED driver for automotive applications

Datasheet - production data



Features

| | | |
|---|-----------|-----|
| Max V_{BATT} | 40 | V |
| Operation supply battery voltage V_{BATT} | 5.6 - 24 | V |
| Oscillator frequency range | 100 - 500 | kHz |

- Automotive qualified
- Constant current operation
- Current LED settable by external sensing resistor and adjustable via SPI
- Converter switching frequency adjustable by external resistor (R_{SF})
- EMC reduction by internal spread spectrum dither oscillator
- Low frequency PWM dimming operation.
- Maximum input current limiter
- Maximum switching duty cycle limiter
- Slope compensation adjustable by external resistor (R_9)
- Battery overvoltage shut down protection (ext. R_3 , R_4 resistors required)
- Led chain OV detection (ext. R_5 , R_6)
- Multiplexed output for monitoring and control of LED temperature (external NTC resistor required), voltage of LED chain, and low frequency PWM
- SPI communication serial interface transceiver (SDI, SDO, SCK, CSN)

- Regulated output for micro supply $5\text{ V} \pm 2\%$ -20 mA
- Parameter programming and settings of internal memory registers by the dedicated SPI interface:
 - LED current reference adjusting ($\pm 66.7\%$)
 - Maximum input current limiter reference adjusting ($\pm 55.5\%$)
 - Random dither frequency sweeping, modulation frequency and deviation percentage
- Power on reset pin output
- ESD protection

Applications

Automotive day time running light, LED HeadLamps

Description

L99LD01 is a precise constant current DC–DC converter LED driver for automotive applications, dedicated to the control of high-brightness LED headlights and housed in a LQFP32™ package.

The device is designed to be used in Boost, Buck-Boost and Fly back converter topologies. An internal random dither oscillator works in low frequency modulation, allowing the RF spectrum of the switching frequency to spread so to reduce EMC emissions. The slope compensation ensures good converter loop stability whatever is the duty cycle needed by the application.

The converter is able to work either in full power mode or in low frequency dimming mode.

The device includes an internal low drop voltage regulator, that can be used to supply a microcontroller, and a reset pin, that is useful for resetting the microcontroller at the start up and every time that the regulated output voltage falls down below an established voltage threshold.

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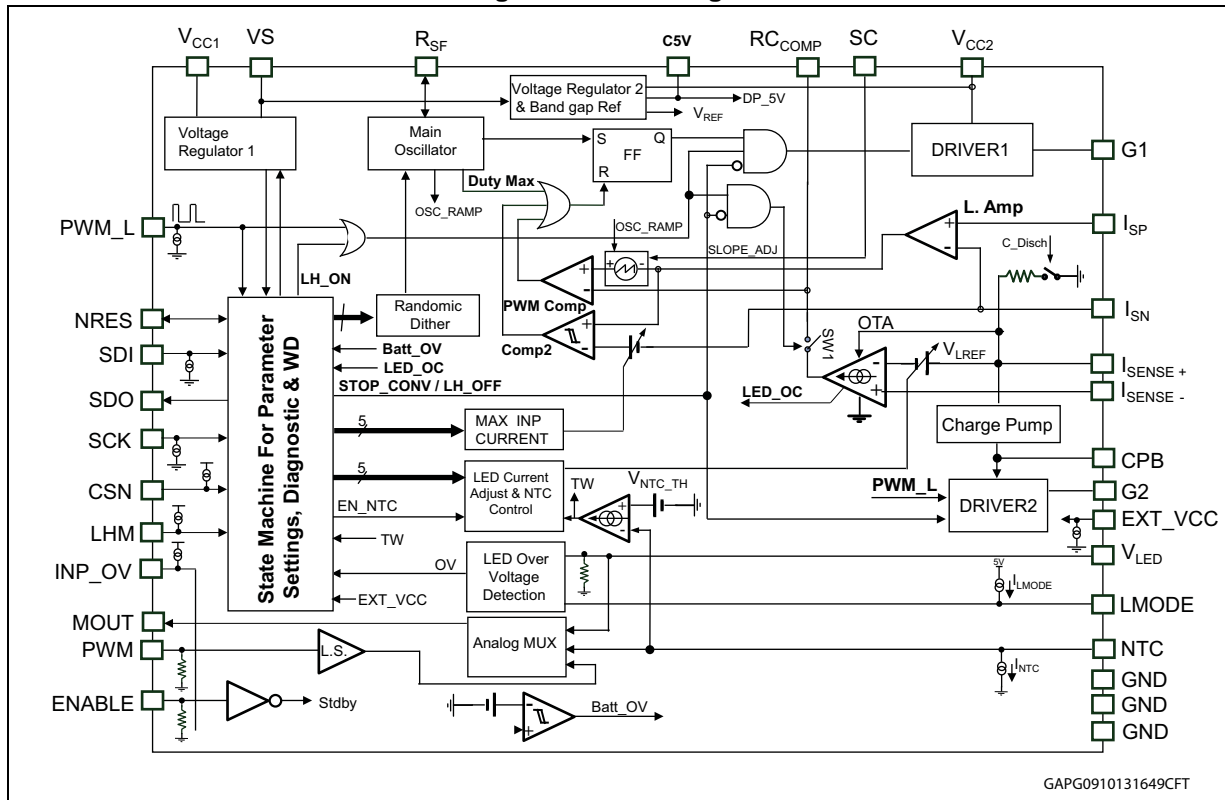
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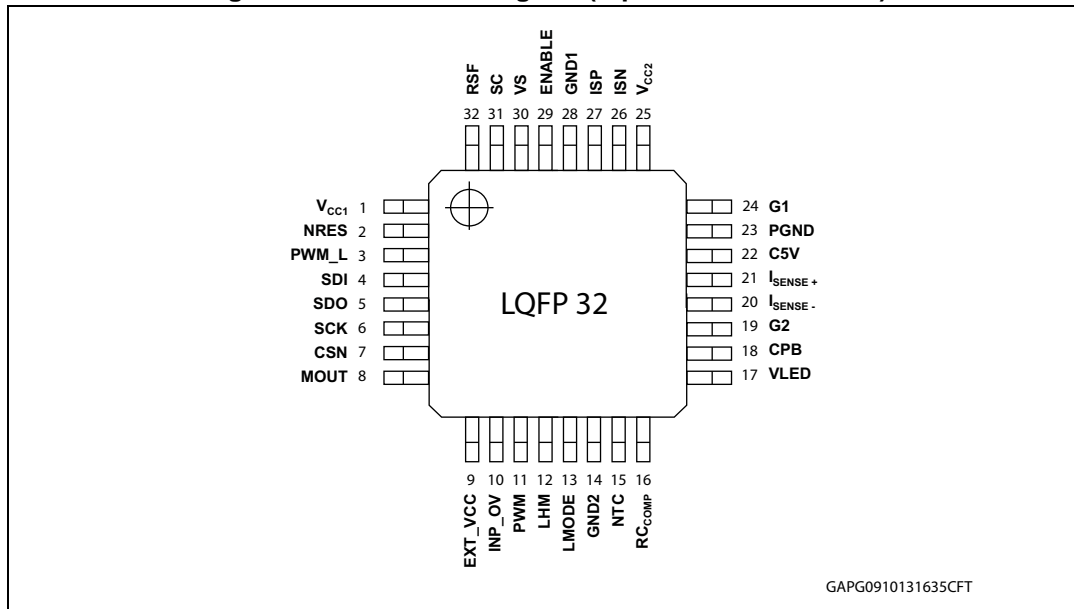
1 Block diagram and pin description

Figure 1. Block diagram



GAPG0910131649CFT

Figure 2. Connection diagram (top view – not in scale)



GAPG0910131635CFT

Table 1. Pin description

| Pin number | Pin name | Function |
|------------|---------------------|---|
| 1 | V _{CC1} | 5 V internal voltage regulator 1 output (external capacitor req.) |
| 2 | NRES | Reset I/O pin; active low |
| 3 | PWM_L | Logic low frequency PWM input |
| 4 | SDI | Serial SPI data input |
| 5 | SDO | Serial SPI data output |
| 6 | SCK | SPI clock |
| 7 | CSN | Chip select not |
| 8 | MOUT | Multiplexed data output pin |
| 9 | EXT_VCC | Internal/external up supply voltage programming pin ⁽¹⁾ |
| 10 | INP_OV | Battery overvoltage programming pin |
| 11 | PWM | Low frequency PWM input (battery compatible) |
| 12 | LHM | Limp home mode input pin |
| 13 | LMODE | Switch input pin (connect to GND if LED drop voltage is referred to GND or open (5 V) if LED drop is referred to V _S) |
| 14 | GND2 | GND of controller |
| 15 | NTC | Output for external N.T.C. resistor |
| 16 | RC _{COMP} | External R C compensation network |
| 17 | VLED | Input for LED chain overvoltage detection |
| 18 | CPB | Charge pump buffer capacitor |
| 19 | G2 | Gate 2 output for external PMOS M2 |
| 20 | I _{SENSE-} | Negative terminal of the LED sense resistor |
| 21 | I _{SENSE+} | Positive terminal of the LED sense resistor |
| 22 | C5V | Output for 5 V buffer capacitor |
| 23 | PGND | Power ground |
| 24 | G1 | Gate 1 output for external PMOS M1 |
| 25 | V _{CC2} | 10 V voltage regulator 2 output (ext. capacitor required) |
| 26 | ISN | Negative terminal of the shunt resistor |
| 27 | ISP | Positive terminal of the shunt resistor |
| 28 | GND1 | GND of controller |
| 29 | ENABLE | Enable pin |
| 30 | VS | Supply voltage input pin |
| 31 | SC | Slope compensation setting resistor |
| 32 | RSF | Oscillator frequency setting resistor |

1. In case of externally supplied microcontroller, attach this pin to its external supply voltage pin.

2 Functional description

2.1 Operating modes

The device is able to work both with a microcontroller and without it (stand alone configuration).

2.1.1 Operation with an external microcontroller

This way allows parameters to be adjusted and checked by means of the SPI interface.

The adjusted device parameters, stored, i.e., inside the micro EEPROM, can be loaded into device internal registers after the start up phase.

By means of a small 8 pins microcontroller it is possible to implement the following functions:

- Parameters setting:
 - LED current level and maximum input current limit can be adjusted according to the application, the LED characteristic and spreads
 - Dither oscillator parameters as random, frequency modulation and deviation percentage can be programmed
- Flexible PWM operation with duty cycle and frequency managed by the microcontroller
- Diagnostic feedback:
 - Fault condition is sent to the micro when the CSN pin is pulled down
- Advanced LED monitoring:
 - LED voltage drop and temperature are multiplexed and sent to the microcontroller through the dedicated MOUT pin in order to monitor the selected parameter with the A/D of the microcontroller. The multiplexer is driven through a SPI command. This function allows a sophisticated control of the LED status. For example, as an alternative to the default overvoltage detection, it is possible to monitor the LED drop voltage, reduced by the external R5/R6 resistor divider. So taking into account the spread and temperature influence on the LED voltage drop, the microcontroller is able to detect if there is one or more LED shorted. Furthermore, it is possible to monitor the LED chain temperature, by means of the voltage feedback through the dedicated NTC pin. The temperature limit control, operated by the device by default, can be disabled via the SPI and the voltage applied on the NTC pin can be sent back to the microcontroller via the multiplexed output, MOUT, so allowing the microcontroller itself to control the LED chain either acting on the internal current LED register or reducing the low frequency PWM duty cycle.
- In case of V_{R1} over temperature, its output will be switched off, the device enters in limp home mode and a failsafe bit will be set in the internal status register (see details in the following paragraph). In order to restart the normal operation, so clearing the corresponding status register bit, the V_S or ENABLE voltage has to be switched off and then on. The mentioned bit can be cleared by the microcontroller only when it is external supplied.

2.1.2 Stand alone operation

The device operates with default parameters. The overall tolerance depends on the internal references precision and the external resistors tolerance. In details:

- LED current via external sensing resistor:

$$I_{LED} = 150 \text{ mV}/R_{SENSE}$$

- Maximum input current via an external shunt resistor.
- Oscillator dither effects are set to its default parameters; a low level on the SDI allows disabling the function.
- Low frequency dimming operation is allowed either by PWM pin or by logic level PWM_L input pin. Connecting the PWM control pin to the supply voltage via a resistor divider, allows the converter to be synchronized to the low frequency PWM generated, i.e., from the smart junction box.
- Connecting the MOUT pin, which by default provides a logic level image of the control input, to the PWM_L input, it is possible to drive the LED according to the PWM frequency and duty cycle of control. (See application circuit of [Figure 38](#)).
- In case of V_{R1} over temperature, its output will be permanently switched off. The device still continues to work in normal mode but with $V_{R1} = \text{OFF}$.

The L99LD01 can operate in 4 different modes:

- Start-up fail
- Normal mode
- Software limp home
- Limp home

After the power on reset, the device stays in start-up phase until V_{CC1} reaches a specified threshold, V_{CC1_TH} . Then the device enters in normal mode either with microcontroller or standalone, depending on the voltage level on the N_{reset} pin.

Note: The information about the operation with microcontroller or standalone is latched until a new power on reset.

If V_{CC1} does not reach both V_{CC1} fail and V_{CC1_TH} thresholds within a given delay or if a V_{CC1} over temperature event occurs, the device enters in a corresponding state.

2.1.3 Start-up fail

The device enters this mode in case a V_{CC1} under voltage event occurs during start-up phase and $V_S < V_{SMIN}$, provided that a microcontroller is detected. In this case V_{CC1} is turned off.

If V_S remains below V_{SMIN} , then the converter is switched off.

If V_S rises above V_{SMIN} , the converter behaves according to the PWM_L pin.

2.1.4 Normal mode

- Normal mode with microcontroller: the device enters this mode after a successful start up ($V_{CC1} > V_{CC1_TH}$) and a microcontroller is detected. The device keeps this mode as long as the watchdog is retriggered before a timeout event.
- Normal mode in standalone configuration: the device enters this mode if a standalone configuration is detected, independently from V_{CC1} errors. The L99LD01 keeps this mode even in case of watchdog timeouts.

In both cases, the converter behaves according to the PWM_L pin.

2.1.5 Software limp home

This device enters software limp home mode in case the Lh_Sw bit is set (see [Section : Control registers 3](#)).

The control registers are set to their default values, with the exception of the Lh_Sw bit, which remains unchanged.

The converter behaves according to the signal on the LHM pin:

- Turned on if a high signal is detected at the LHM pin
- Turned off if a low signal is detected at the LHM pin

2.1.6 Limp home mode

The device enters limp home mode, if a microcontroller is detected, in the following cases:

- Watchdog timeout in normal mode
- V_{CC1} under voltage ($V_{CC1} < V_{CC1_TH}$) for more than 2 ms in normal mode
- V_{CC1} is below the V_{CC1_FAIL} threshold for more than 4 ms during start-up
- V_{CC1} is below V_{CC1_uv} for more than 100 ms during start-up and V_S is above V_{SMIN} threshold
- Thermal shutdown of V_{CC1}
- SDI stuck at 0 or 1

In Limp Home mode, all the control registers are set to their default values, except Lh_Sw (see [Section : Control registers 3](#)), which remains unchanged.

The converter behaves according to the voltage level on the LHM pin:

- Turned on if a High signal is detected at the LHM pin
- Turned off if a Low signal is detected at the LHM pin

Depending on the root cause, the action taken to quit the limp home mode (provided that the limp home condition has disappeared) is different. Some of the recovery paths require the microcontroller to be supplied by external supply.

A power on reset is always possible.

Figure 3. Operating modes, main states

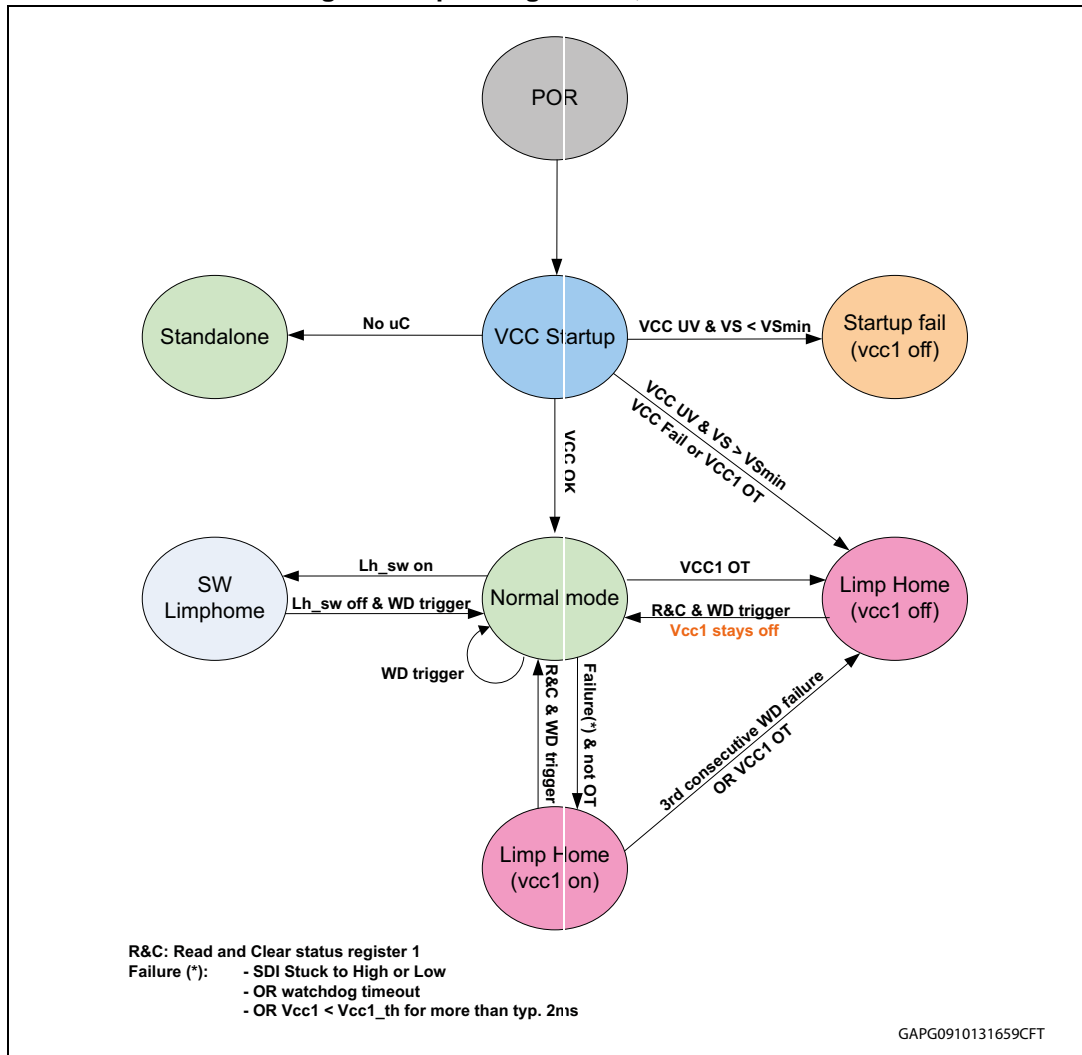


Table 2. Limp home mode: recovery paths

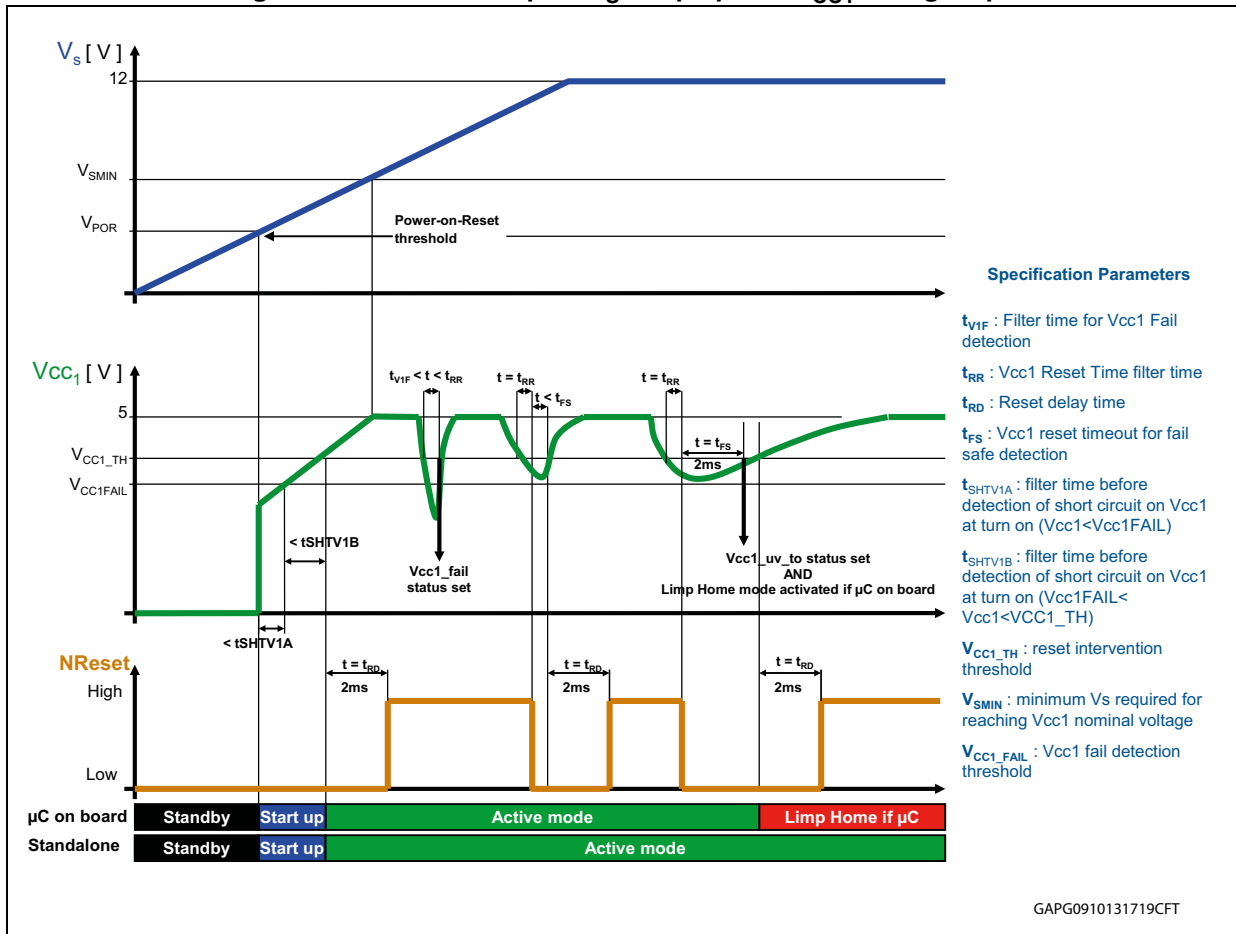
| Transition | Root cause | Action to get back to normal mode | Response in the next SPI command |
|---|--|---------------------------------------|---|
| Normal mode → Limp Home V _{CC1} on | WD timeout (1 st or 2 nd WD timeout) | Read and clear status1 AND WD trigger | Fail Safe bit = 0 WD_Fail bit = 0 |
| | V _{CC1} < V _{CC1_TH} for more than 2 ms | | Fail Safe bit = 0 Vcc1_Uv_To bit = 0 |
| | SDI stuck at 0 or 1 | | Fail Safe bit = 0 SDI_Stuck@ = 0 |

Table 2. Limp home mode: recovery paths (continued)

| Transition | Root cause | Action to get back to normal mode | Response in the next SPI command |
|---|--|---|---|
| Limp home V_{CC1} on → limp home V_{CC1} off | 3 consecutive WD timeouts (microcontroller is supplied by V_{CC1}) | Power on reset OR toggling of EN pin | Fail Safe bit = 0 WD_Fail bit = 0 Reset bit = 1 |
| | 3 consecutive WD timeouts (microcontroller is supplied by another V_{REG}) | Read and clear Status1 AND WD trigger | Fail Safe bit = 0 WD_Fail bit = 0 |
| Start up → limp home V_{CC1} off | $V_{CC1} < V_{CC1_FAIL}$ during start up for more than 4 ms | Power on reset | Failsafe bit = 0 Vcc1_Sc bit = 0 Reset bit = 1 |
| | $V_{CC1} < V_{CC1_FAIL}$ during start up for more than 4 ms (microcontroller supplied by another V_{REG}) | Read and clear Status1 AND WD trigger OR Toggling of EN pin | Failsafe bit = 0 Vcc1_Sc bit = 0 Vcc1_Fail = 0 |
| | $V_{CC1} < V_{CC1_TH}$ for more than 100 ms during start up AND $V_S > V_{SMIN}$ | Power on reset OR toggling of EN pin | Fail Safe bit = 0 Vcc1_Sc bit = 0 Reset bit = 1 |
| | $V_{CC1} < V_{CC1_TH}$ for more than 100 ms during start up AND $V_S > V_{SMIN}$ (microcontroller supplied by another V_{REG}) | Read and clear Status1 AND WD trigger | Fail Safe bit = 0 Vcc1_Sc bit = 0 |
| Any state except normal mode standalone → limp home V_{CC1} off | V_{CC1} over temperature | Read and clear Status1 AND WD trigger | Fail Safe bit = 0 Vcc1_Ot bit = 0 |
| Normal mode → SW limp home | Software limp home is activated | Reset Lh_Sw bit AND WD trigger | Fail Safe bit = 0 Lh_Sw_St = 0 |

The following [Figure 4](#), [Figure 5](#) (a), (b) and [Figure 6](#) (a) show the behavior of the device and NRES during start-up in case of normal V_S ramp up or in case of V_{CC1} failures (V_{CC1} fail or reset under voltage), both with microcontroller and standalone. [Figure 6](#) (b) and [Figure 7](#) show the behavior at V_S ramp down fast and slow respectively.

Figure 4. Normal start up vs V_S ramp up and V_{CC1} voltage dips



Note: Normal start up with or without microcontroller.

Figure 5. V_{CC1_FAIL} or V_{CC1} reset under voltage ($V_S > V_{SMIN}$) at start up

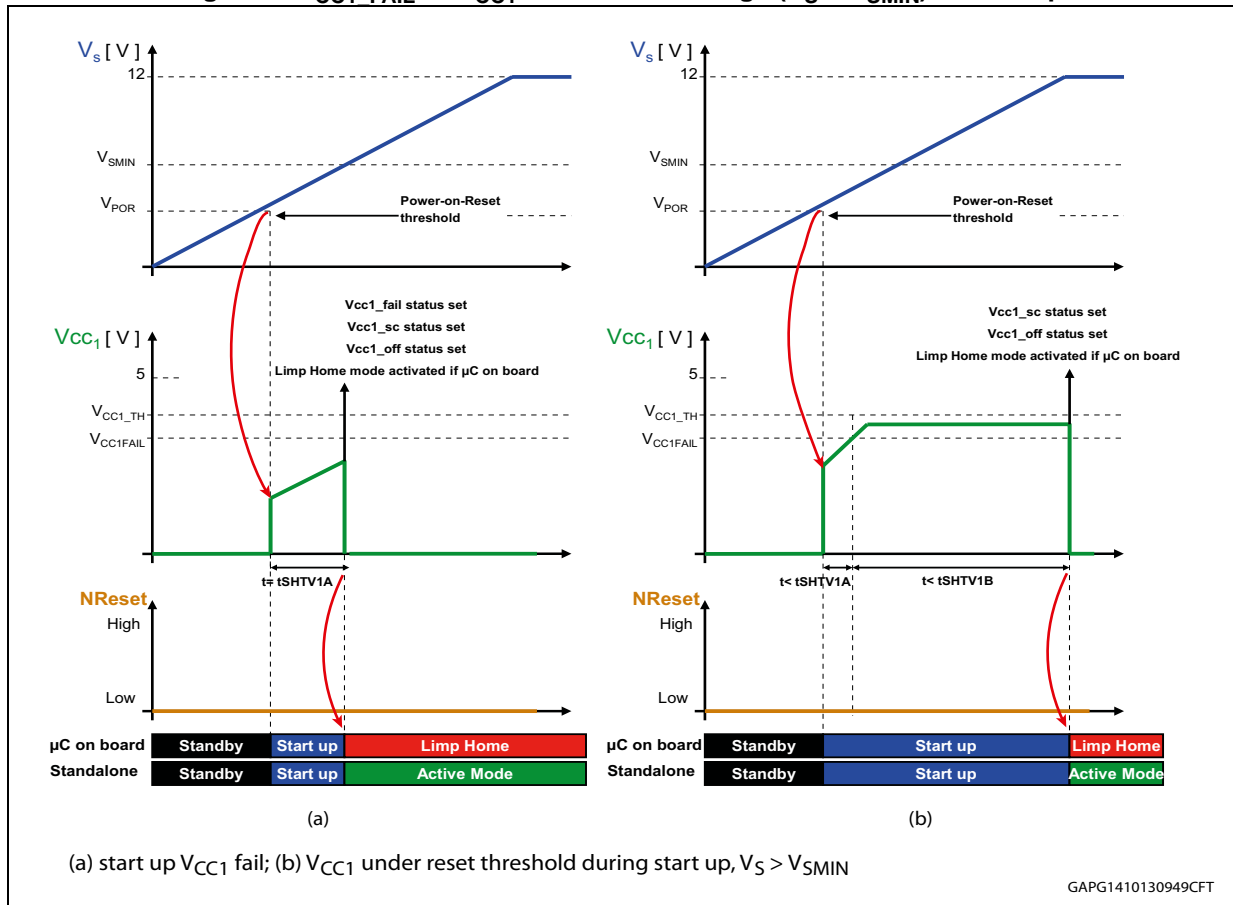
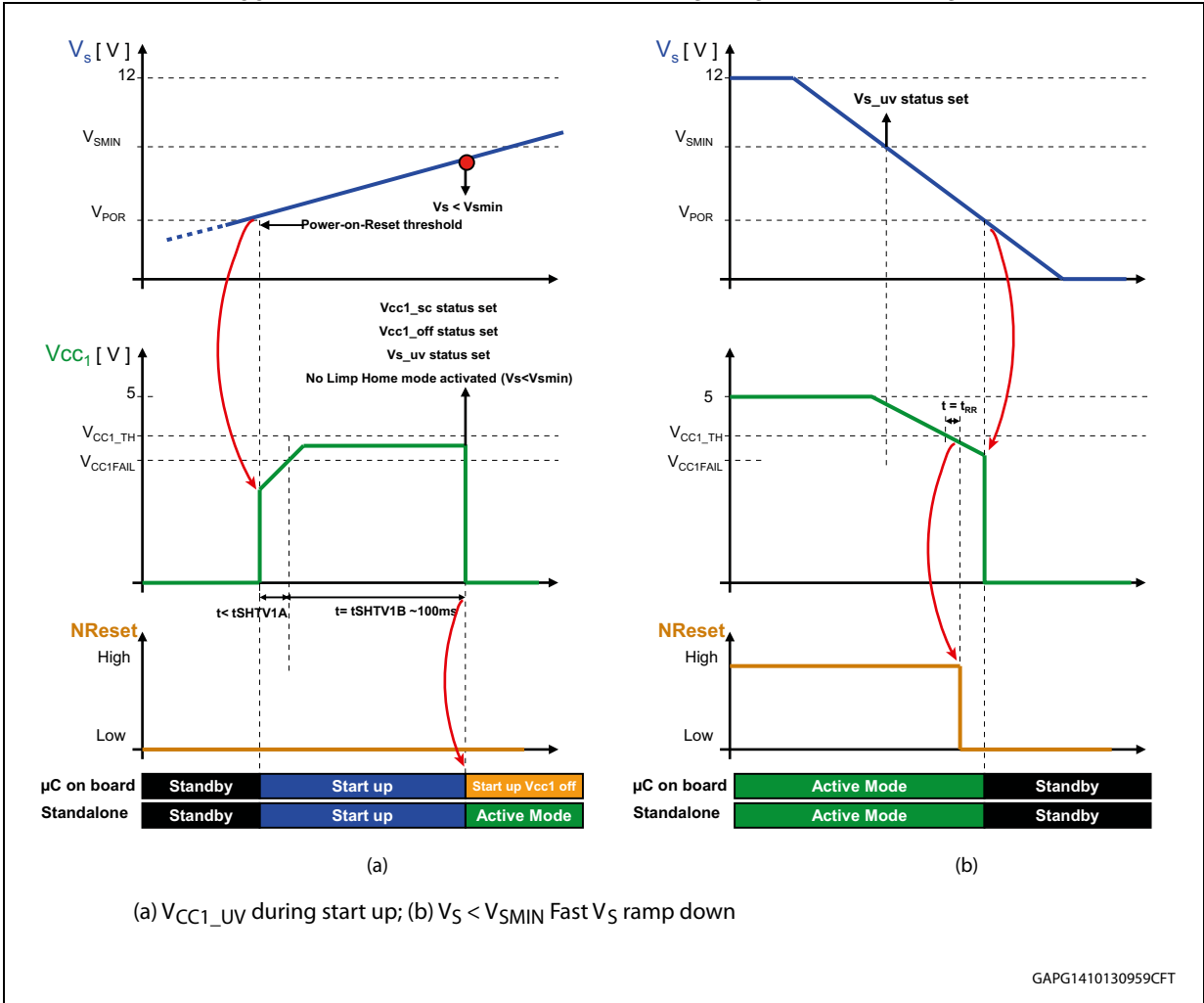


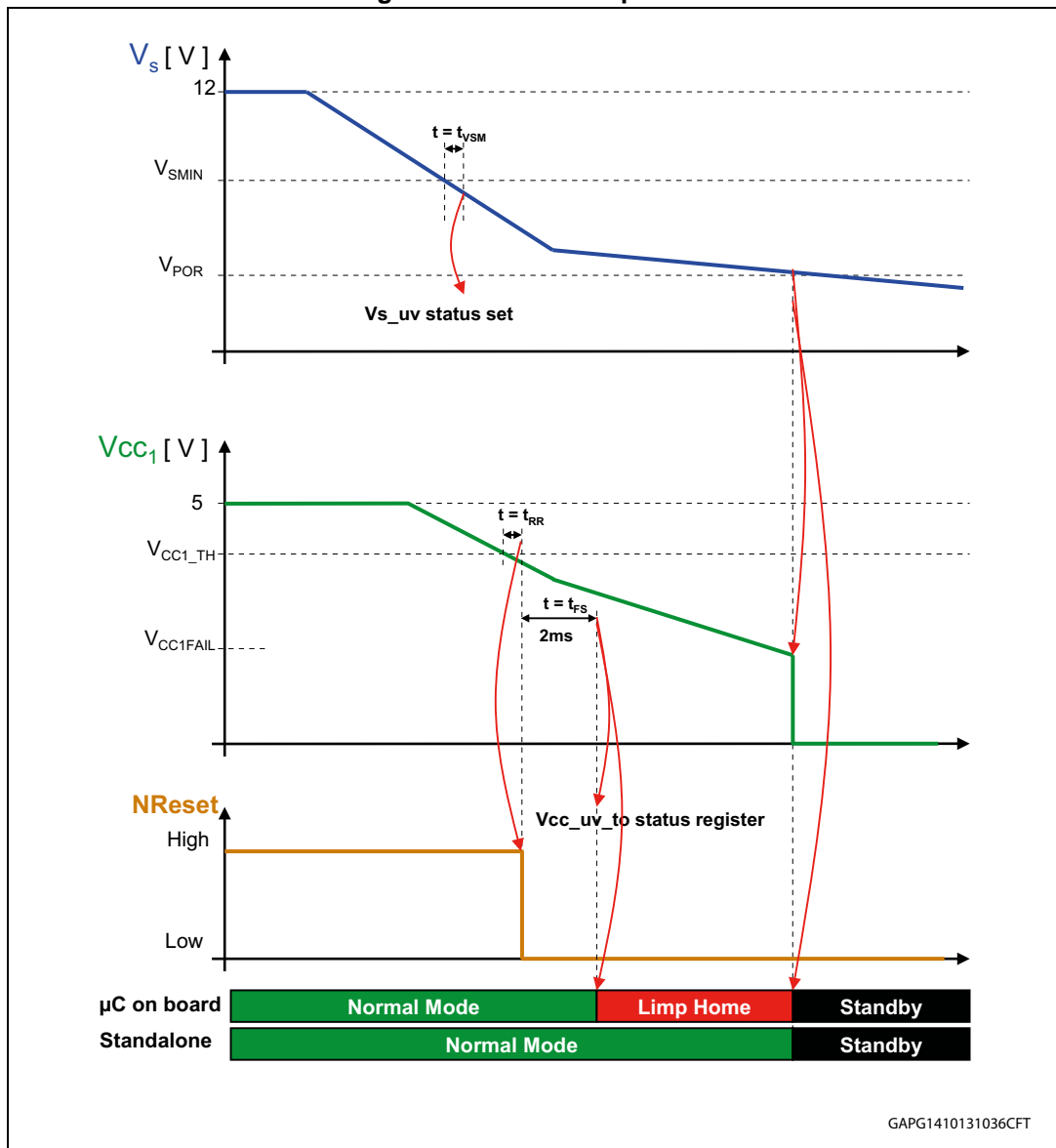
Figure 6. V_{CC1} reset under voltage at start up ($V_S < V_{SMIN}$) and fast V_S ramp down



(a) V_{CC1_UV} during start up; (b) V_S < V_{SMIN} Fast V_S ramp down

GAPG1410130959CFT

Figure 7. Slow vs ramp down



2.2 Protections and functions

2.2.1 LED current adjust and temperature control

The LED current can be adjusted within a range of $\pm 66.7\%$, with respect to the default value set by the LED current sense resistor, via the SPI input, so allowing the end of line calibration. The LED chain temperature measurement is achieved by means of an external NTC resistor connected between the NTC pin and GND. The NTC resistor is supplied through a resistor connected to the 5 V internal regulator output. As soon as the voltage on the NTC resistor becomes lower than the internal threshold, V_{NTC_TH} , (due to an overtemperature in the LED chain) an internal circuitry is activated and the internal LED current reference voltage decreases proportionally, so that the LED current is progressively

reduced (maximum 50 % of the nominal LED current), not allowing the LED temperature to increase over the programmed limit.

Thermal limit intervention is reported by properly setting a bit inside the internal status register.

2.2.2 Slope compensation

Slope compensation is needed to ensure the stability of the control loop with all possible values of duty cycle

$$D = \frac{T_{ON}}{T}$$

($0 < D < 1$)

especially for duty cycle greater than 0.5. The recommended slope S_{ADD} of the additional ramp is proportional to the inductor current slope during the turn off phase, that is:

$$S_{ADD} = \alpha \cdot S_L$$

where S_{ADD} is the additional slope introduced by the circuit,

$$S_L = \left. \frac{dI_L}{dt} \right|_{OFF}$$

is the off-time inductor slope and

$$0.5 < \alpha < 1$$

S_L is also given by the formula:

$$S_L = \frac{G_{LA} \cdot R_{SHUNT} \cdot (V_{OUT} - V_{IN})}{L}$$

Being G_{LA} the gain of the linear amplifier (see [Chapter 5: Electrical characteristics](#) for G_{LA} parameter values) and R_{SHUNT} is the resistor across pin I_{SP} and I_{SN} (see [Chapter 7: Application circuits](#)).

The simplified internal circuit structure for the slope compensation is shown in [Figure 8](#).

The additional slope is obtained from the internal oscillator ramp voltage. A fraction of the oscillator voltage ramp is added to the output voltage of the sensing amplifier, which is proportional to the sense resistor voltage drop, and therefore, to the current flowing through power mosfet M1.

The added ramp voltage is

$$V_{ADD} = I \cdot R_{SLOPE}$$

where

$$I = 2 \cdot \frac{V_{OSC}}{R_T}$$

and R_{SLOPE} and R_T are defined in the [Figure 8](#), together with their typical values.

Therefore, will result:

$$V_{ADD} = 2 \cdot V_{OSC} \cdot \frac{R_{SLOPE}}{R_T}$$

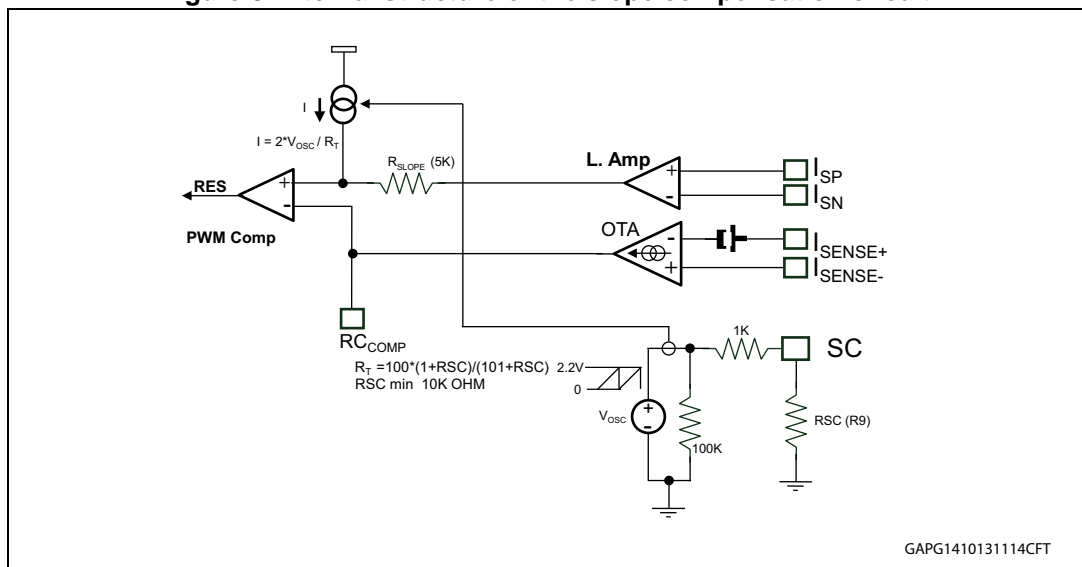
and consequently:

$$S_{ADD} = \frac{V_{ADD}}{T} = \frac{2 \cdot V_{OSC} \cdot R_{SLOPE}}{R_T \cdot T}$$

where T is the period of the converter oscillator.

The additional compensating current slope can be simply adjusted by properly setting the value of the external resistor R9 (and consequently R_T).

Figure 8. Internal structure of the slope compensation circuit



2.2.3 LED chain overvoltage detection

Via the external resistor divider (R5, R6) it is possible to detect LED overvoltage events, by programming a threshold for the maximum drop voltage of the LED chain for a specific LED board (see [Section 2.2.12](#) for details). In case Boost or Fly back topology is used, the L_{MODE} pin must be connected to GND. In this case the voltage at pin V_{LED} will be referred to ground. Instead, if Buck Boost topology is used, the L_{MODE} pin must be connected to 5 V or left open. An internal pull up current source keep this pin high, and in this case, the voltage applied by the resistor divider R5/R6 at pin V_{LED} will be referred to the battery voltage applied at pin V_S . If a valid overvoltage event occurs, which is detected if the LED drop voltage reaches a value $V_{LED} \geq OV_TH1$, the device is switched off immediately forcing the

pins G1 and G2 to zero voltage and the event is registered in the status register of the SPI interface and read by the micro.

In case of LED overvoltage, immediately after stopping the device, an internal resistor is applied between pin I_{SENSE+} and GND through the switch "C_disch" (see [Figure 1](#)), in order to discharge capacitors C1 and C4, avoiding LED flashing when the converter restarts. Any LED_OV event will be written in the GSB (Global Status Byte) bit 7 and also in the SR1 (Status Register 1) bit 18.

2.2.4 Battery overvoltage shutdown

In case supply voltage applied to the V_S pin rises above a maximum voltage threshold, sensed by a resistor divider attached at pin INP_OV, the converter is switched off immediately, forcing outputs pin G1 and G2, to zero voltage. This prevents a LED over current in case of load-dump.

If, following the input overvoltage event, the battery voltage decreases under a second threshold, lower than the former, the converter starts again.

2.2.5 Regulators thermal shut down

Both voltage regulators inside the chip are provided with over temperature detection circuits.

If V_{R1} reaches its maximum temperature, V_{R1} will be switched off. After that, the behavior of the device depends on the application (see [Section 2.2.1: LED current adjust and temperature control](#)).

If instead, is V_{R2} to reach its maximum temperature (typ 175 °C), then the device will be completely switched off (V_{CC1} and V_{CC2} = 0).

Only the internal temperature monitoring of V_{CC2} remains alive and when the temperature falls down under a second lower temperature threshold (150 °C typ.), the device tries to restart again.

2.2.6 Reset

The NRES pin (active low), generates a reset signal for the microcontroller.

An external pull up resistor (typ. 100 k) maintain normally high the voltage at pin NRES (see [Figure 32](#)).

Following a power up condition, the NRES pin is forced low while the voltage provided by regulator 1 (V_{CC1}) is below an internal fixed threshold V_{CC1_TH} of typ 4.5 V. After V_{CC1} has reached the above mentioned internal threshold, NRES voltage is kept low for a fixed default time of 2 ms; after that, the NRES pin will be released reaching the normal high state. However, this time can be externally extended by an additional capacitance connected between NRES and GND (see C6 in the application circuits), which is charged by the external pull-up. Depending on the reset-input-threshold of the μP (U_{TR}), the required capacitance for a typical T_{RD} can be calculated as follows:

$$C6 = -T_{RD} / (R_{PU} \cdot \lg(1 - U_{TR}/V_{CC1}))$$

R_{PU} is the pull up resistor (value in ohm)

In case V_{CC1} voltage drops below the internal threshold during the normal functioning, or when the device is put in standby, the NRES pin is forced to low, but after a time interval T_{RR} has expired and kept low until the V_{CC1} has gone back again to the internal threshold (see [Figure 4](#) for more details).

2.2.7 Watchdog

In case the application uses a microcontroller, during the device power-up a reset pulse is generated periodically every 200 ms (default) for 2.0 ms waiting for microcontroller acknowledgment. Timeout window is selectable by SPI (100 ms or 200 ms) and the reset time could be extended by the external capacitor C6.

- Timeout WD is refreshed by bit toggling.
- After the 1st WD timeout, a reset pulse is generated and the device enters in Limp Home mode. After the second WD timeout, another reset pulse cycle is generated, waiting for microcontroller response.
- After 3 consecutive reset cycles without WD refresh, which means that microcontroller is not responding, the voltage regulator, V_{CC1} , is turned off and the device keeps working in “Limp Home Mode” (see [Figure 33](#)). Safety critical functions like Low Beam application require the LED Driver to be turned on if the microcontroller fails, while in case of high beam application, it is required the driver to be switched off in case of microcontroller failure. As a consequence, the device operates according to the state of LHM pin which is enabled during the recognition of the microcontroller failure. In particular, if LHM pin is kept low the device will be always OFF. If instead, LHM pin is high or left open, the device will be switched permanently ON, regardless of the status of PWM_L pin. If the application doesn't use a microcontroller (stand alone operation), the start-up WD control must to be deactivated. This can be done by connecting NRES pin to the battery supply voltage V_S . In such a case the driver will operate in normal mode as above mentioned (see stand alone operation).

2.2.8 Standby and wake up by ENABLE pin

A low consumption mode is required in case of applications directly connected to the battery.

The device enters in standby mode, that is the default operating modes because of an internal pull down, in case of low level signal at the ENABLE pin and it wakes up in case of high level signal. During standby mode, V_{CC1} and V_{CC2} are switched off. [Figure 9](#) and [Figure 10](#) show two possible application schematics in case of direct connection to the battery.

In case of [Figure 9](#) the microcontroller of the application goes in standby when the microcontroller sets the LIN transceiver in standby mode: NSLP = Low → INH goes Low → the DRL driver goes in standby.

The application is waken up from the standby when a wake up source is detected by the LIN transceiver. That means INH goes high and so ENABLE, then the DRL driver restarts and consequently V_{CC1} is activated and supplies the microcontroller.

In case of [Figure 10](#), a power management device is present, which supplies the microcontroller. Normally the inverted FSO signal coming from the power management device is high. This output is inverted by an external logic and applied to one of the two input OR diodes and therefore, at the input of the OR the voltage is normally at logical zero.

So in this case the LED driver goes:

- In stand-by mode with a low level on ENABLE pin operated by the microcontroller
- In normal mode with a high level on ENABLE pin operated by the microcontroller

The inverted FSO signal, coming from the power management device ensures, putting through the inverter and the external OR diode ENABLE pin high, that the LED driver correctly restarts even if the microcontroller fails.

Figure 9. Operation with a standalone LIN and ENABLE

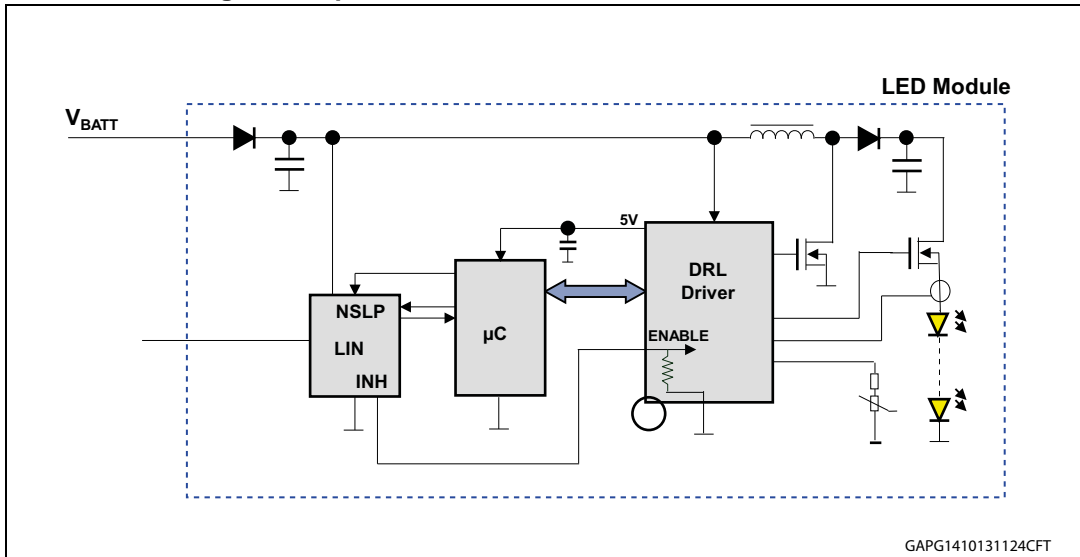
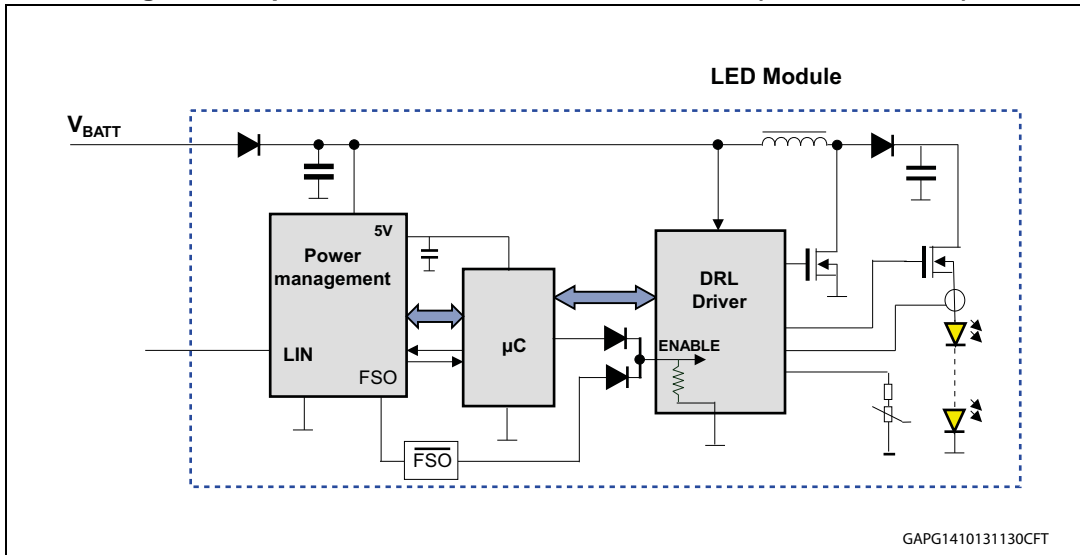


Figure 10. Operation with PM device and ENABLE (FSO active Low)



1. An inverter network is required.

2.2.9 Frequency setting and dither effect

The internal main converter oscillator structure is reported in [Figure 11](#).

The external resistor applied between pin R_{SF} and ground is setting the converter working frequency. The voltage applied on pin R_{SF} is the internal reference reported by the source follower structure which is a constant voltage of 1.21 V. The converter frequency is directly related to the current flowing through the R_{SF} pin. *Figure 12* reports the behavior of frequency converter as function of the external resistor R_{SF} and I_{RSF} as function of converter frequency. As above mentioned the converter oscillator spread parameters (dither effect) are adjustable via SPI.

Dither effect is disabled by default during standalone operation, but it is possible enabling it simply connecting the SDI pin to 5 V voltage.

Figure 11. Internal structure of main converter oscillator

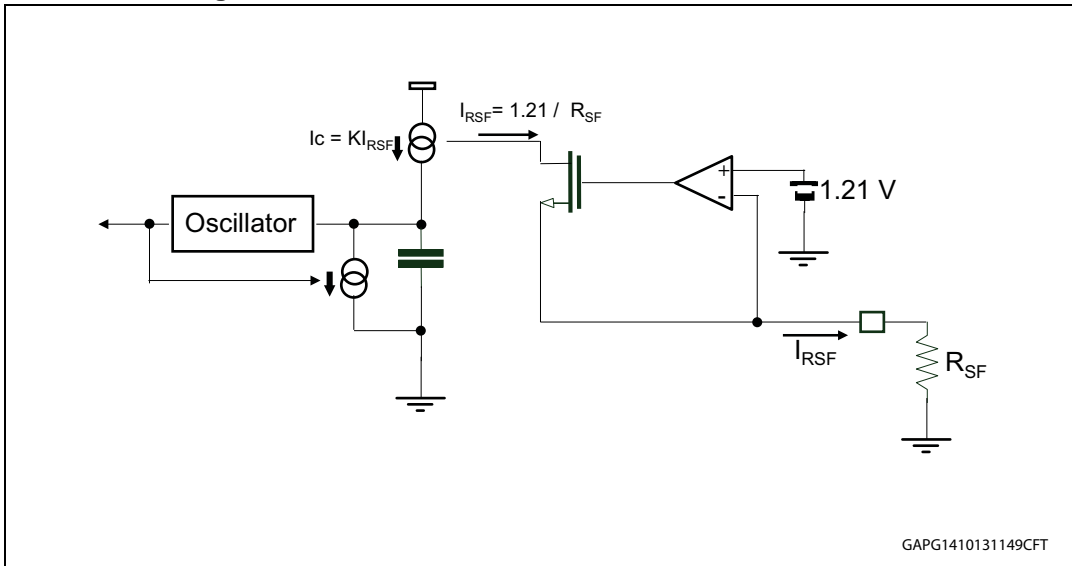
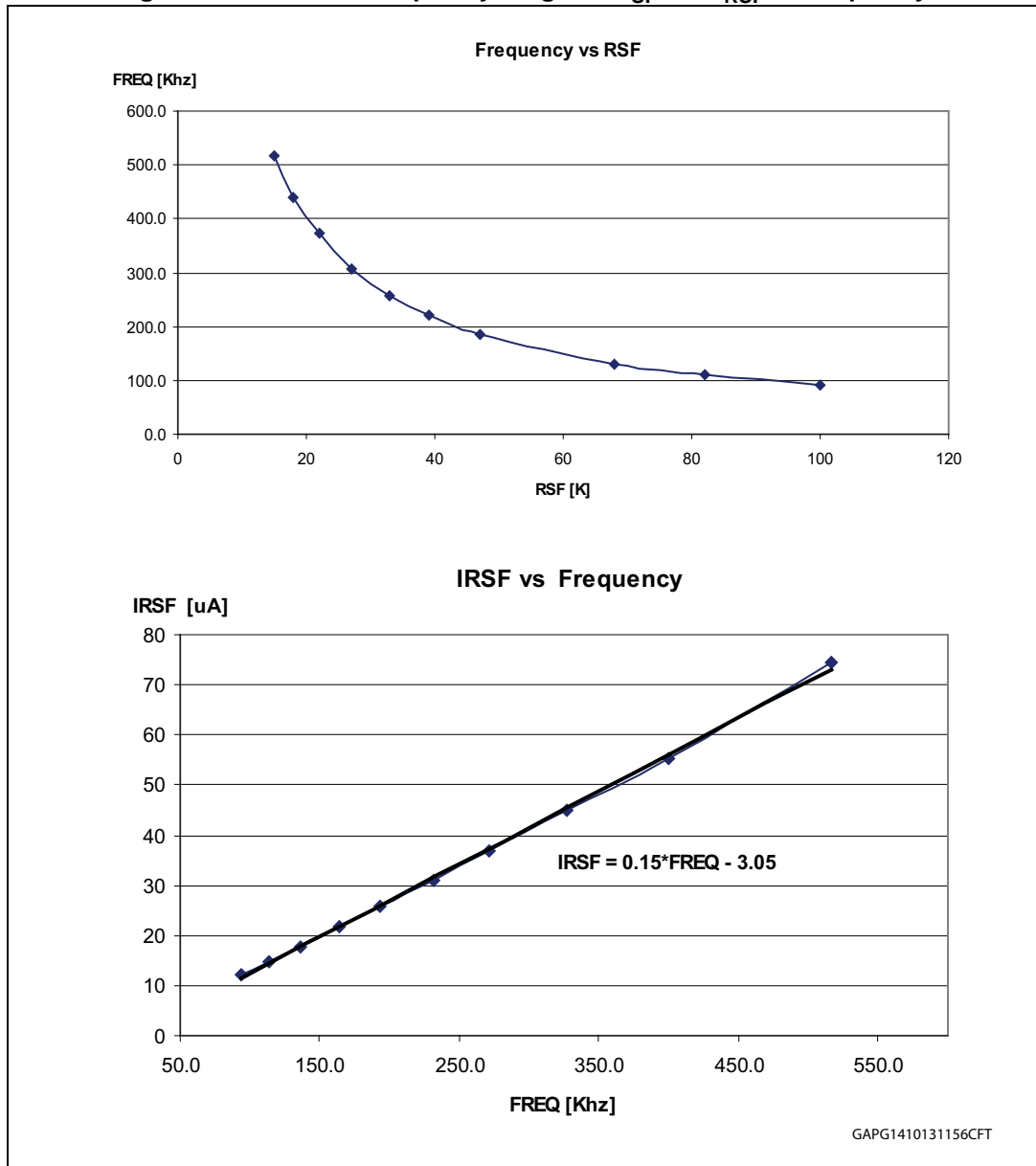


Figure 12. Converter frequency range vs R_{SF} and I_{RSF} vs frequency



2.2.10 Start up LED overvoltage management

The following diagram shows the purpose of delay time windows “ t_{DStart} ” and “ $t_{EnRecov}$ ”.

The first delay window t_{DStart} has been thought to ensure an initial time period for charging the external buffer capacitor of the charge pump C9. When V_S is below V_{SMIN} , the LED overvoltage recovery bit is set. During this time interval, triggered as soon as the battery voltage V_S overcomes V_{SMIN} threshold, the converter remain in a stop condition, independently from PWM_L. When the t_{DStart} is elapsed (typ. 5 ms), the converter is released and behaves according to the PWM_L signal provided, that no failure occurs.

If no LED overvoltage comes during the 2nd time interval $t_{EnRecov}$, LED ov recovery bit is reset.

If a LED overvoltage failure occurs afterwards, the failure will be latched and the converter is stopped until a read and clear of the status register 1.

Note that during t_{DStart} , the converter is stopped to enable the buffer capacitor C9 to charge at a sufficient voltage to correctly drive the mosfet M2. This delay prevents the converter to turn on, while M2 stays off, avoiding a LED overvoltage event.

If the application uses a big capacitor^(a), it is recommended to keep the PWM_L signal low after a power on reset or after a V_S under voltage, until C9 is totally charged, to avoid a LED overvoltage. [Figure 13](#) shows the device behavior in case of no LED overvoltage failure, after t_{DStart} .

If C9, after t_{DStart} time, should be not enough charged to allow correct driving operation, a possible LED overvoltage will appear when, the converter will be released. [Figure 14](#) shows what happens in this case.

After t_{DStart} , the converter is released while the C9 capacitor is only partially charged. Consequently, V_{LED} increases up to LED OV_TH1 and a LED overvoltage event is detected during the $t_{EnRecov}$ phase. The LED_Ov_Rec bit is not reset at the end of the $t_{EnRecov}$ phase due to the LED overvoltage event. The discharge path is activated until V_{LED} crosses LED OV_TH2. Then, the LED_Ov_Rec bit is reset, the converter is released, and the buffer capacitor C9 is now fully charged, enabling the dimming mosfet M2 to turn on.

[Figure 15](#) shows the case of LED_Ov_Rec bit during a start up with a rising edge on PWM_L = High after the expiration of t_{DStart} . In this case, the $t_{EnRecov}$ phase starts only when the PWM_L signal goes High. [Figure 16](#) shows the case of LED overvoltage event, which could appear during normal functioning.

The LED overvoltage status bit is set (latched) and the discharge path is activated until V_{LED} crosses LED OV_TH2. The converter is stopped, independently from PWM_L, until a read and clear command of the status register 1 (LED_Ov_Rec bit is reset).

If a LED overvoltage failure event occurs during V_S overvoltage, (battery OV), the discharge path for the output capacitor is inhibited and the LED overvoltage status bit is not set.

When the V_S overvoltage event disappears, (V_S crosses V_S OV_TH2), the LED overvoltage status bit is set (latched) and the discharge path is activated until V_{LED} crosses LED OV_TH2. The converter is stopped, independently from PWM_L, until the LED ov status bit is cleared (read and clear of the status register 1). [Figure 17](#) shows such a case.

Finally [Figure 18](#) shows how will be managed the LED_Ov_Rec bit in case signal PWM_L has a low on-time. In this case the LED_Ov_Rec bit is reset when the cumulated running time of $t_{EnRecov}$ exceeds typ. 5 ms. This feature enables a single recovery of a LED overvoltage event, due to a too fast regulation loop (set by the resistor and capacitor connected to RCCOMP pin), even in PWM operation with low on-time. However, a proper choice of RC network values, avoiding fast transients on the LED string voltage, when the converter is switched ON, it is carefully recommended

a. More than 22 nF

Figure 13. Correct start UP with no LED overvoltage failure

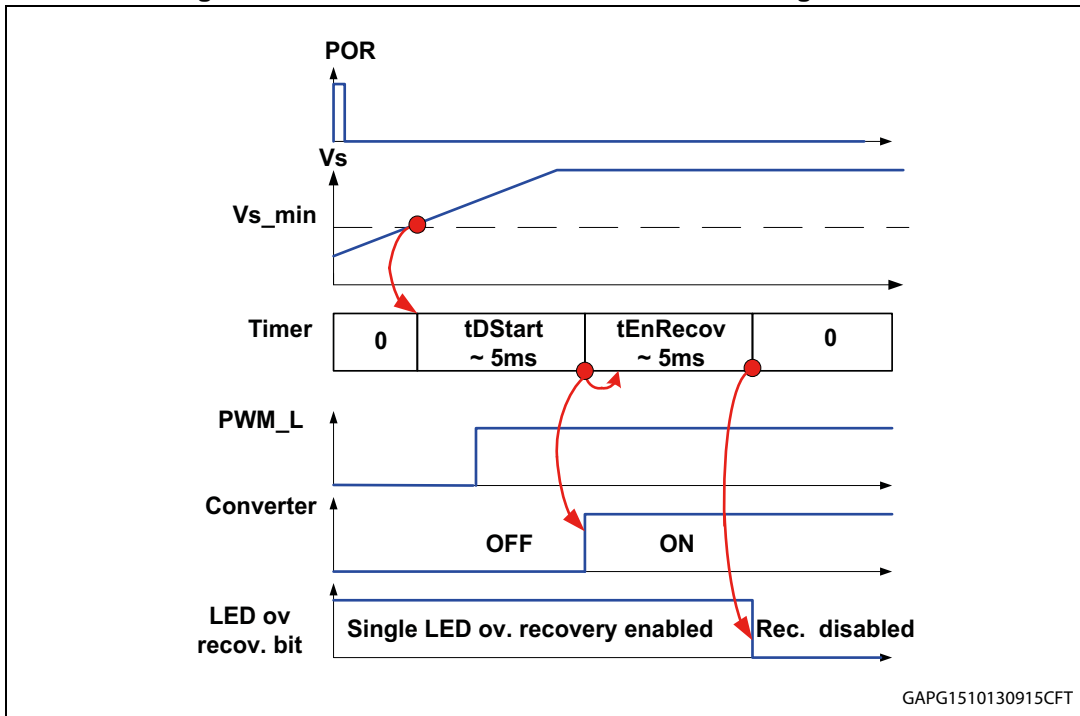


Figure 14. LED overvoltage after t_{DStart}

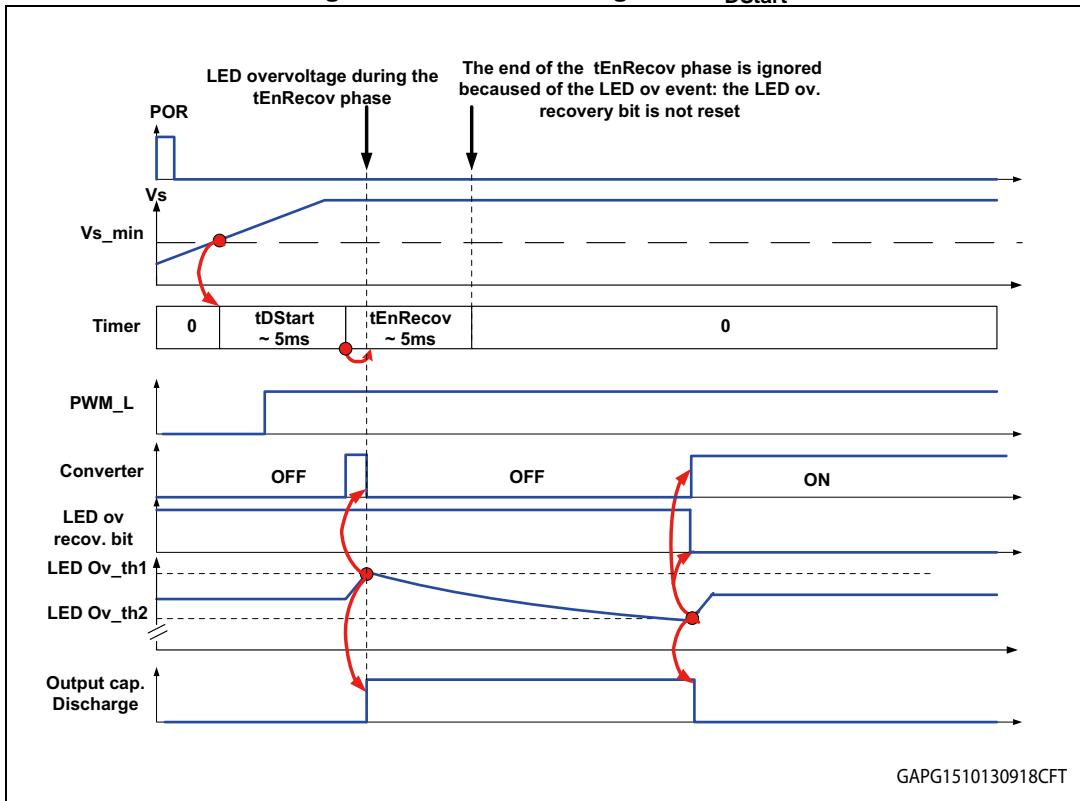


Figure 15. Device behavior in case the low to high transition of PWM_L signal happens after t_{DStart} expiration

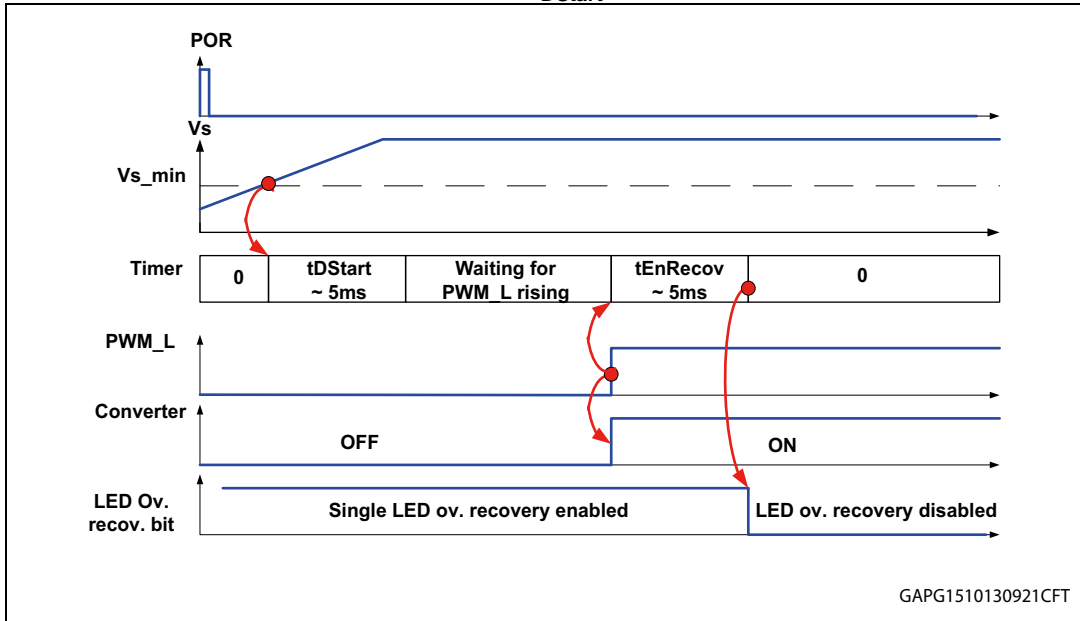


Figure 16. LED overvoltage event not caused by a VS overvoltage event

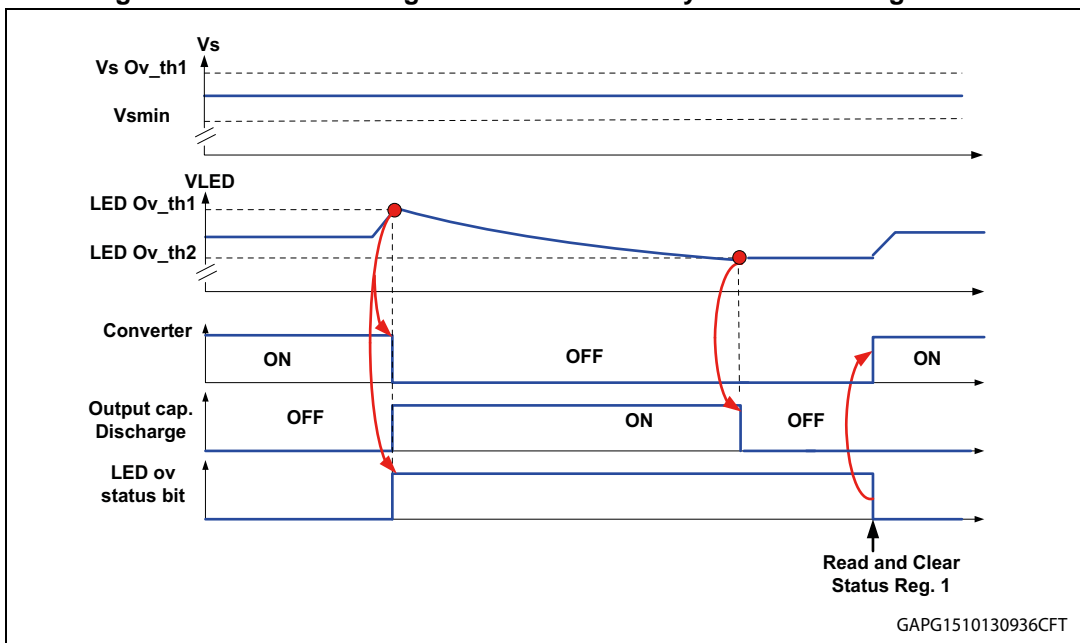


Figure 17. LED overvoltage detection due to a possible battery VS overvoltage

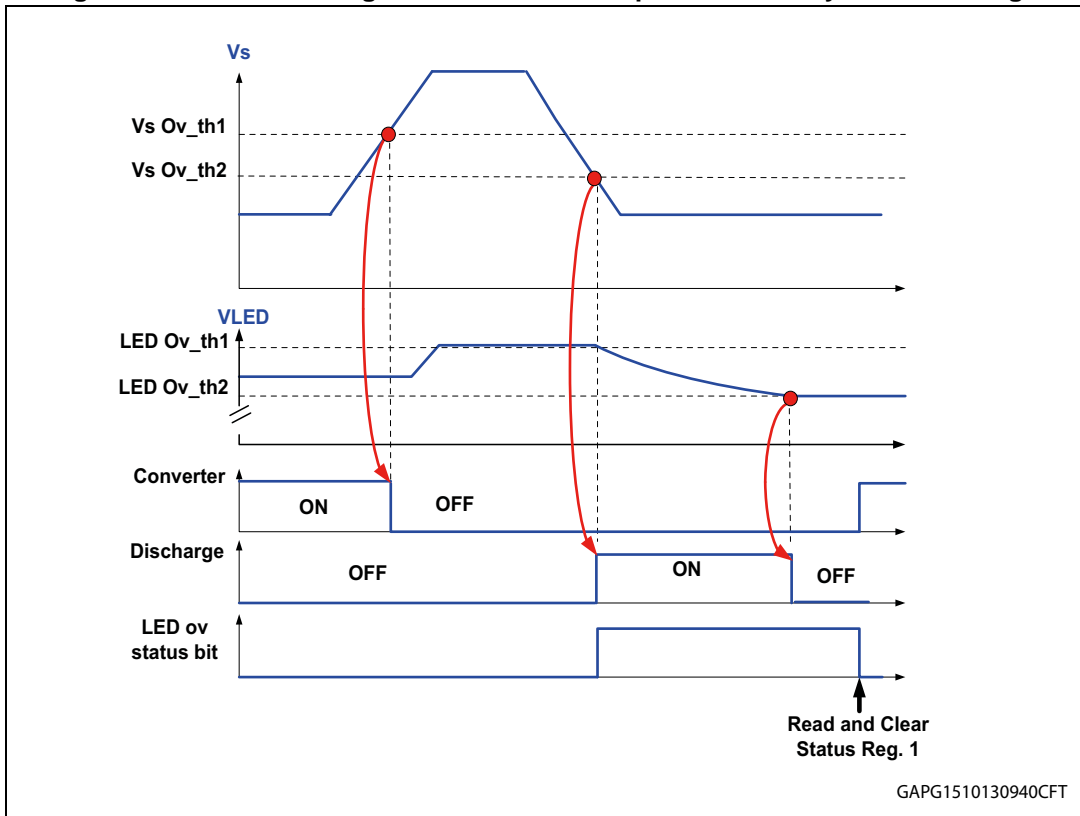
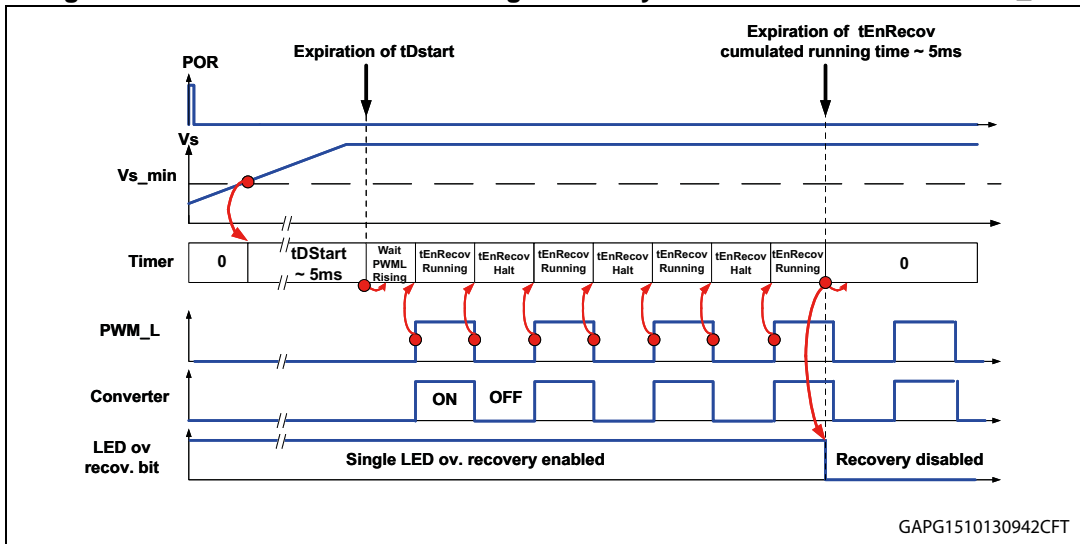


Figure 18. Behavior of LED overvoltage recovery bit with low on-time of PWM_L



2.2.11 Programming the over/under voltage threshold

The voltage across the LED string is continuously sensed by the external resistor divider R5/R6 and reported inside the chip through the apposite pin V_{LED} . Considering negligible the voltage drop due to the sense resistor and the V_{DS} of external mosfet M2 respect to the LED

voltage string, according to the equation reported below, the LED overvoltage thresholds are given by the following formulas:

$$V_{LED_OV} = OV_TH1 / K_L; \text{ being } K_L = R_6 / (R_5+R_6);$$

OV_TH1 is the reference for the OV internal comparator. Typical value for OV_TH1 is 3.5 V.

LED OV event makes the converter and also mosfet M2 immediately switched OFF, in order to prevent any damage to the LED string or to the driver. Furthermore, following an OV event, the LED_OV status register is set and an internal load is applied between I_SENSE+ pin and ground in order to fast discharge the voltage across capacitor C4.

In the boost topology application, if a short circuit between the source of external mosfet M2 and GND occurs, an uncontrolled current could flow. In order to avoid this situation, a maximum LED current protection has been inserted, which continuously monitors the voltage across the sense resistor R_SENSE. If this voltage reaches a value in excess of an internal fixed threshold of (see Table 24 - LED over current protection threshold parameter), the status bit LED_OC (led over current) is set and the converter and also mosfet M2 will be immediately switched OFF.

Following a stop of the converter due to an OV event, the device can not be restarted before of C4 discharge (V_LED is below OV_TH2).

After an OV event, the converter could restart if a read and clear command of the LED_OV status bit is done. Table 3 summarizes the suggested value of K_L resistor ratio, supposing to have a LED_OV event, when the voltage across LED string, reaches a value in excess of 50 % of its nominal value.

Figure 19. LED chain overvoltage thresholds settings. An example for boost and fly back converters

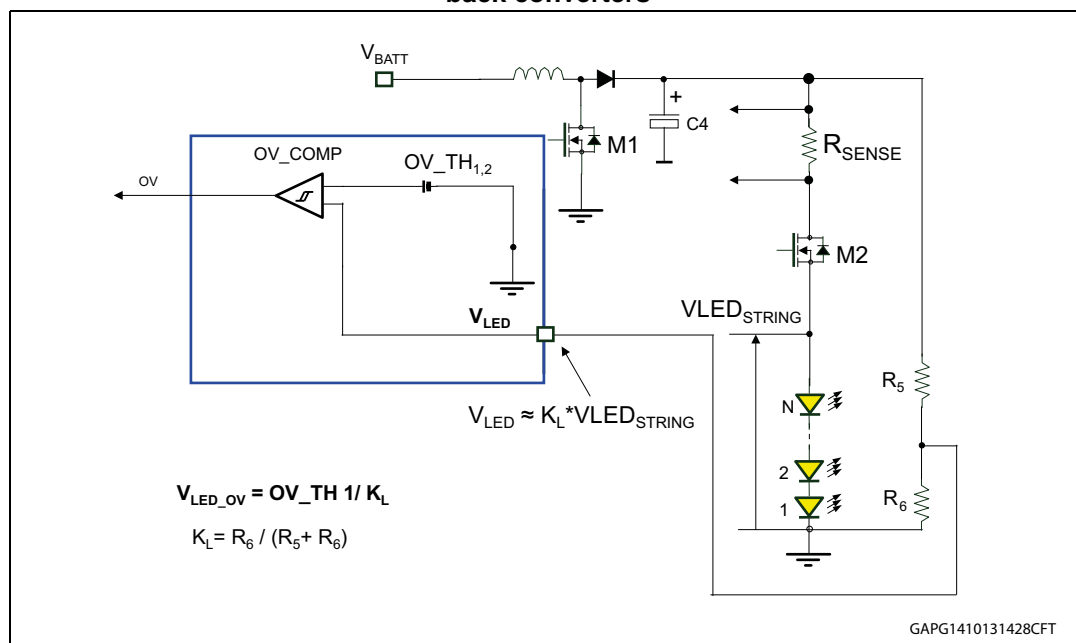


Table 3. Suggested K_L value and overvoltage thresholds

| N Number of LED | K_L | LED CHAIN nominal DROP $N \cdot V_F$ [V] | overvoltage V_{LED_OV} [V] |
|--------------------|--------|---|-------------------------------|
| 1 ⁽¹⁾ | 0.583 | 4 | 6 |
| 2 ⁽¹⁾ | 0.292 | 8 | 12 |
| 3 ⁽¹⁾ | 0.194 | 12 | 18 |
| 4 ⁽¹⁾ | 0.146 | 16 | 24 |
| 5 | 0.117 | 20 | 30 |
| 6 | 0.097 | 24 | 36 |
| 7 | 0.083 | 28 | 42 |
| 8 | 0.073 | 32 | 48 |
| 9 | 0.065 | 36 | 54 ⁽²⁾ |
| 10 | 0.0583 | 40 | 60 ⁽²⁾ |

1. Not Applicable on boost converter topology, since the chain LED Drop must be always larger as the maximum battery voltage.
2. Theoretical value; effective value will be clamped to 52 V (typ) by the OV protection.

2.2.12 Input overvoltage programming

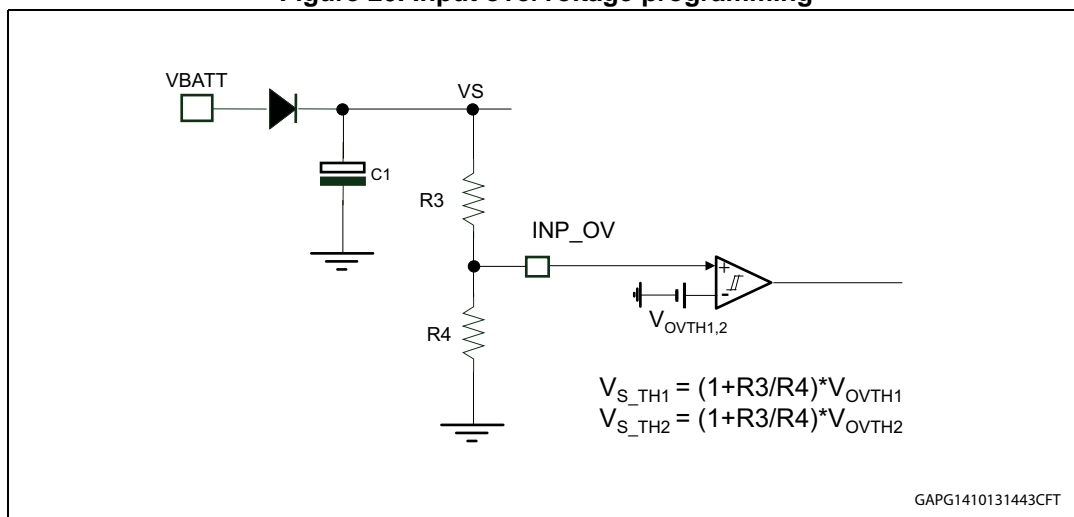
Supply overvoltage is programmed by the external partition ratio $K_I = R3/R4$

According to the [Figure 20](#) input overvoltage thresholds depend on the internal reference voltages V_{OVTH1} and V_{OVTH2} (being $V_{OVTH2} < V_{OVTH1}$)

Typical values of these internally generated references are 3.5 V and 3 V.

When the Battery voltage reaches a value in excess to V_{S_TH1} the converter is immediately stopped. When the battery voltage, going down, reaches a value just lower to V_{S_TH2} , the converter restarts again.

Figure 20. Input overvoltage programming



As an example, if we want $V_{S_TH1} = 20$ V, according to the formula of [Figure 20](#), $R3/R4$ will result equal to 4.7 and consequently the deactivation threshold V_{S_TH2} will result ~ 17 V.^(b)

b. Notice that the deactivation threshold must be always greater than the maximum allowed battery value in normal conditions.

3 SPI functional description

3.1 Serial peripheral interface (ST SPI standard)

The SPI communication is based on a standard ST-SPI 24-bit interface, using CSN, SDI, SDO and SCK signal lines.

Input data are shifted into SDI, MSB first while output data are shifted out on SDO, MSB first.

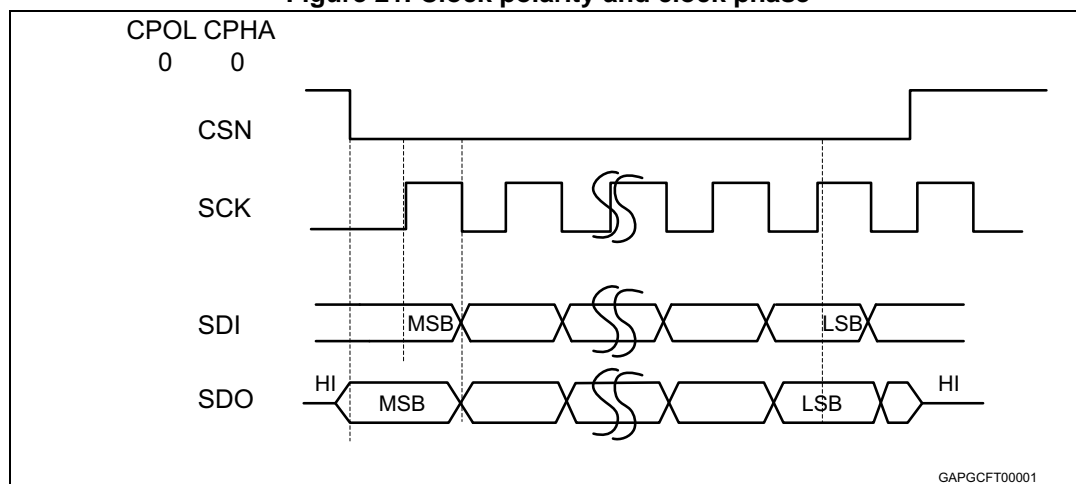
During active mode, the SPI:

- Triggers the watchdog
- Controls the modes and status of all internal modules (incl. input and output drivers)
- Provides driver output diagnostic
- Provides device diagnostic (incl. over temperature warning, device operation status)

Note: During standby modes, the SPI is generally deactivated.

The SPI can be driven by a microcontroller with its SPI peripheral running in following mode:

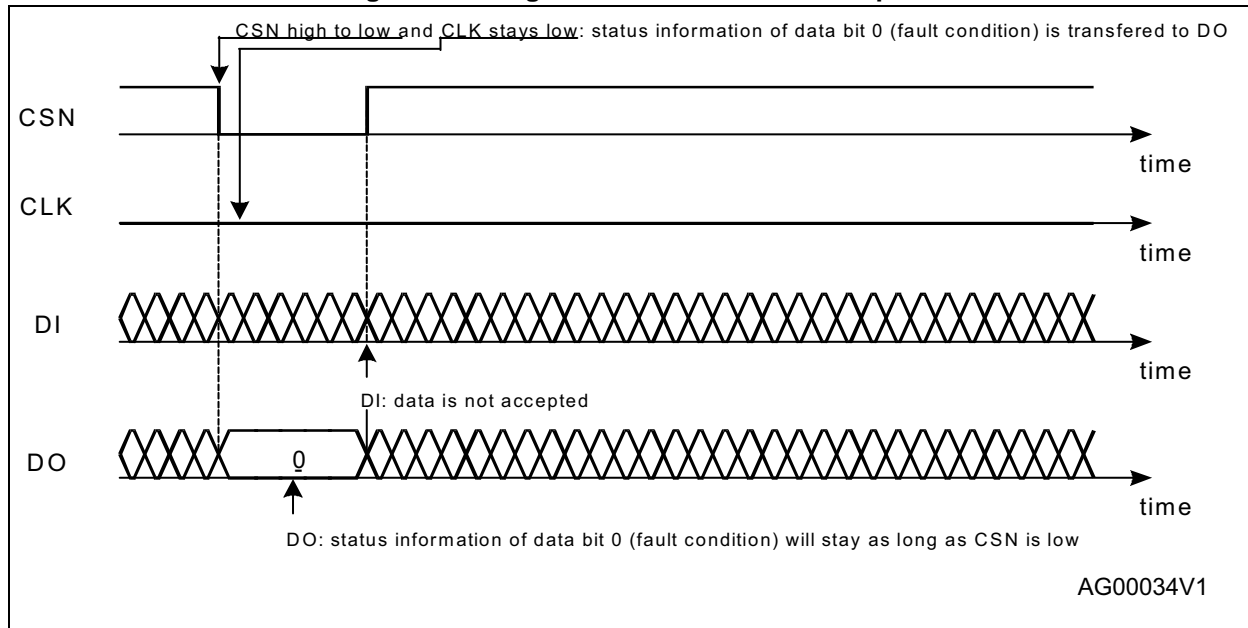
Figure 21. Clock polarity and clock phase



According to the standard, a generic input bit is sampled by the low to high transition of the clock CLK and a generic output bit changes synchronously to the high to low transition of CLK.

This device is not limited to micro controller through a built-in SPI. Only three CMOS-compatible output pins and one input pin will be needed to communicate with the device. A fault condition can be detected by setting CSN low. If CSN = 0, the DO pin will reflect the global error flag (fault condition) of the device (see [Figure 22](#)). This operation does not cause a communication error bit in the global status byte to be set.

Figure 22. SPI global error information output



3.2 Signal description

- Serial Clock (SCK): this input signal provides the timing of the serial interface. Data present at Serial Data Input (SDI) is latched on the rising edge of Serial Clock (SCK). Data on Serial Data Out (SDO) is shifted out at the falling edge of Serial Clock (SCK).
- Serial Data Input (SDI): This input is used to transfer data serially into the device. It receives the data to be written. Values are latched on the rising edge of Serial Clock (SCK).
- Serial Data Output (SDO): this output signal is used to transfer data serially out of the device. Data is shifted out on the falling edge of Serial Clock (SCK). SDO also reflects the status of the <Global Error Flag> (Bit 7 of the <Global Status Register>) while CSN is low and no clock signal is present
- Chip Select Not (CSN): when this input signal is High, the device is deselected and Serial Data Output (SDO) is high impedance. Driving this input Low enables the communication. The communication must start and stop on a Low level of Serial Clock (SCK).

3.3 SPI protocol

3.3.1 SDI, SDO format

SDI format during each communication frame starts with a command byte.

It begins with two bits of operating code (OC0, OC1) which specify the type of operation (read, write, read and clear status, read device information) and is followed by a 6 bit address (A0:A5). The command byte is followed by an input data byte (D0:D15).

At the beginning of each communication the master device read the contents of the <SPI-frame-ID> register (ROM address 3Eh) of the slave device. This 8 bit register indicates the SPI frame length (24 bit) and the availability of additional features.

Each communication frame consists of a command byte which is followed by 2 data bytes.

The data returned on SDO within the same frame always starts with the <Global Status Byte>. It provides general status information about the device. It is followed by 2 data bytes (i.e. "in-frame-response").

For write cycles the <Global Status Byte> is followed by the previous content of the addressed register.

Table 4. Command byte (8 bit)

| Bit | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|------|-----|-----|----|----|----|----|----|----|
| Name | OC1 | OC0 | A5 | A4 | A3 | A2 | A1 | A0 |

Table 5. Input data byte

| Bit | Data Byte 1 | | | | | | | | Data Byte 0 | | | | | | | |
|------|-------------|-----|-----|-----|-----|-----|----|----|-------------|----|----|----|----|----|----|----|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Name | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |

SDO format during each communication frame starts with a specific byte called Global Status Byte (see [Section 3.3.2](#)). This byte is followed by two output data byte (D0:D7, D8:D15).

Table 6. Global status byte

| Bit | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|------|-----|----------|--------------------------------|--------------|---------------|-------------|------------------------|-----------|
| Name | GEF | Comm_Err | Not (chip reset or Comm_Error) | LED overload | Temp. warning | Overvoltage | V _{CC1} Error | Fail safe |

Table 7. Output data byte

| Bit | Data Byte 1 | | | | | | | | Data Byte 0 | | | | | | | |
|------|-------------|-----|-----|-----|-----|-----|----|----|-------------|----|----|----|----|----|----|----|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Name | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |

3.3.2 Global status byte description

The data shifted out on SDO during each communication starts with a specific byte called Global Status Byte. This one is used to inform the microcontroller about global faults which can be happened on the channel part (like thermal warning, OVL,...) or on the SPI interface (like communication error,...). This specific register has the following format.

Table 8. Global status byte

| Bit | Name | Description |
|-----|------------------------------|---|
| 23 | Global Error Flag (GEF) | This bit is an OR combination of the remaining bits of the register OR (Vs_uv) OR (Lmode_err) |
| 22 | Comm_Err | The right number of SPI clocks within any valid spi command is 24. If not, then this bit is set to '1'. This bit goes to '0' automatically after any valid spi command |
| 21 | Not (Chip reset OR Comm Err) | After a POR phase this bit is active ('0'). It becomes inactive ('1') after the first valid spi command, provided that any communication error occurs. |
| 20 | LED Overload | This bit is set when an LED overcurrent event is detected |
| 19 | Temp. warning | Temperature Warning for the LED |
| 18 | Overvoltage | LED chain overvoltage or Vs overvoltage via INP_OV (Led_Ov OR Vs_Overvoltage) |
| 17 | V _{CC1} Error | This bit is an OR combination of all the errors related to V _{CC1} |
| 16 | Fail Safe | This bit is set if the device is in a limp home mode (Data In stuck at '0' or '1', watchdog time out, software limp home), V _{CC1} undervoltage for more than 2 ms in active mode. |

3.3.3 Operating code definition

The SPI interface features four different addressing modes which are listed in [Table 10](#).

Table 9. Operation code definition

| OC1 | OC0 | Meaning |
|-----|-----|---------------------------------|
| 0 | 0 | Write operation |
| 0 | 1 | Read operation |
| 1 | 0 | Read and clear status operation |
| 1 | 1 | Read device information |

The <Write Mode> and <Read Mode> operations allow access to the RAM of the device.

A <Read and Clear Mode> operation is used to read a status register and subsequently clears its content.

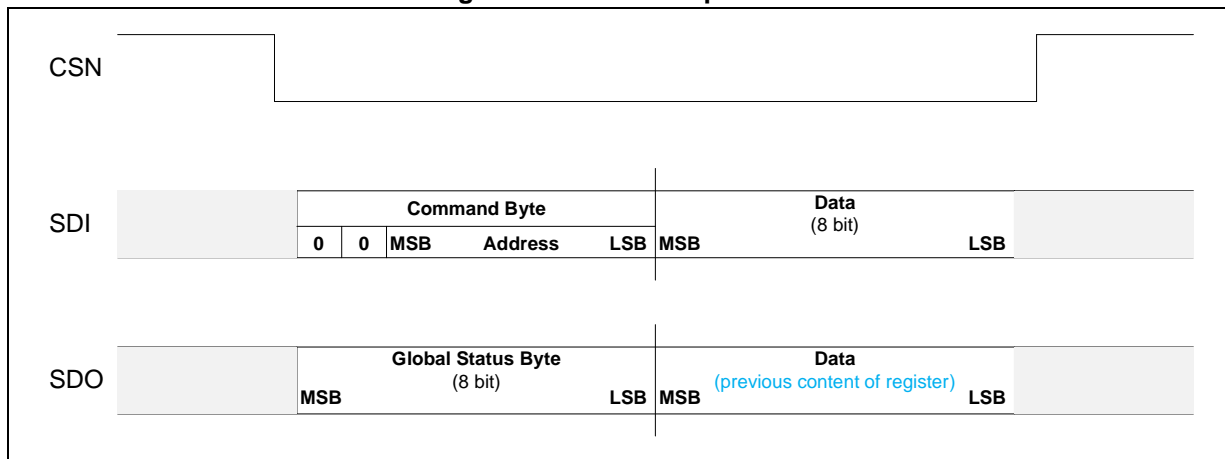
The <Read Device Information> allows access to the ROM area which contains device related information such as <ID-Header>, <Product Code>, <Silicon Version> and <SPI-frame-ID>.

Write mode

The write mode of the device allows writing the content of the input data byte into the addressed register. Incoming data are sampled on the rising edge of the serial clock (SCK), MSB first.

During the same sequence outgoing data are shifted out MSB first on the falling edge of the CSN pin and subsequent bits on the falling edge of the serial clock (SCK). The first byte corresponds to the Global Status Byte and the second to the previous content of the addressed register.

Figure 23. SPI write operation

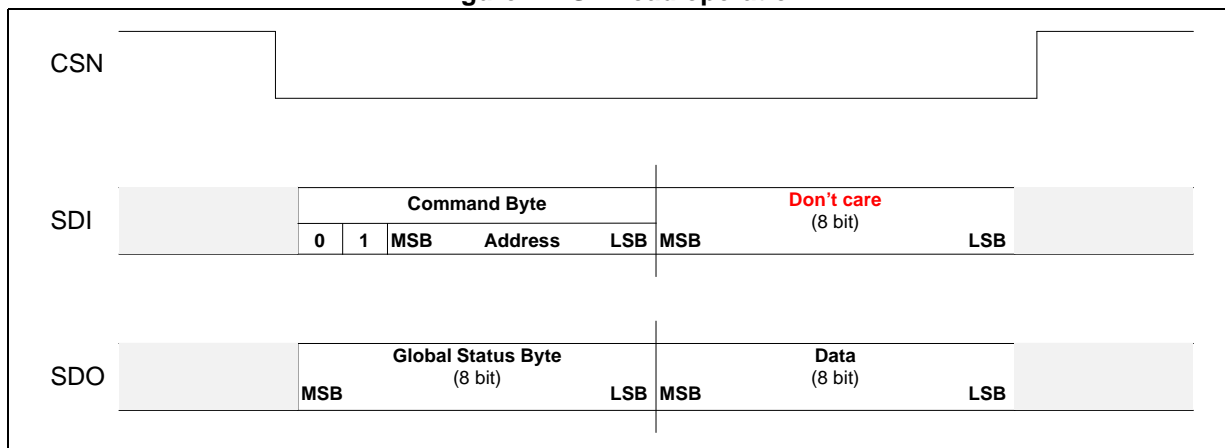


Read mode

The read mode of the device allows to read and to check the state of any register. Incoming data are sampled on the rising edge of the serial clock (SCK), MSB first. Outgoing data are shifted out MSB first on the falling edge of the CSN pin and others on the falling edge of the serial clock (SCK). The first byte corresponds to the Global Status Byte and the second to the content of the addressed register. In case of a read mode on an unused address, the 'global status/error' byte on the SDO pin is following by 00H byte.

In order to avoid inconsistency between the Global status byte and the status register, the status register contents are frozen during SPI communication.

Figure 24. SPI read operation



Read and clear status command

The read and clear status operation is used to clear the content of the addressed status register (see [Section : Status registers 1](#)). A read and clear status operation with address

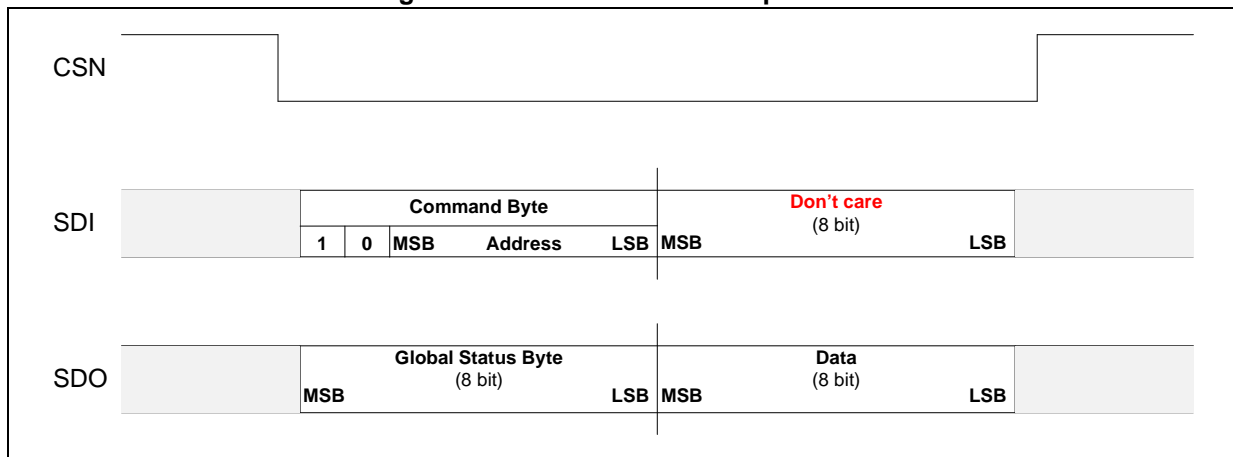
3Fh clears all status registers simultaneously and reads back the configuration register (GLOBCTR).

Incoming data are sampled on the rising edge of the serial clock (SCK), MSB first. The command byte allows to determine which register content is read then erased while the data byte is 'don't care'.

Outgoing data are shifted out MSB first on the falling edge of the CSN pin and others on the falling edge of the serial clock (SCK). The first byte corresponds to the Global Status byte and the second to the content of the addressed register.

In order to avoid inconsistency between the Global status byte and the status register, the status register contents are frozen during SPI communication.

Figure 25. SPI read and clear operation



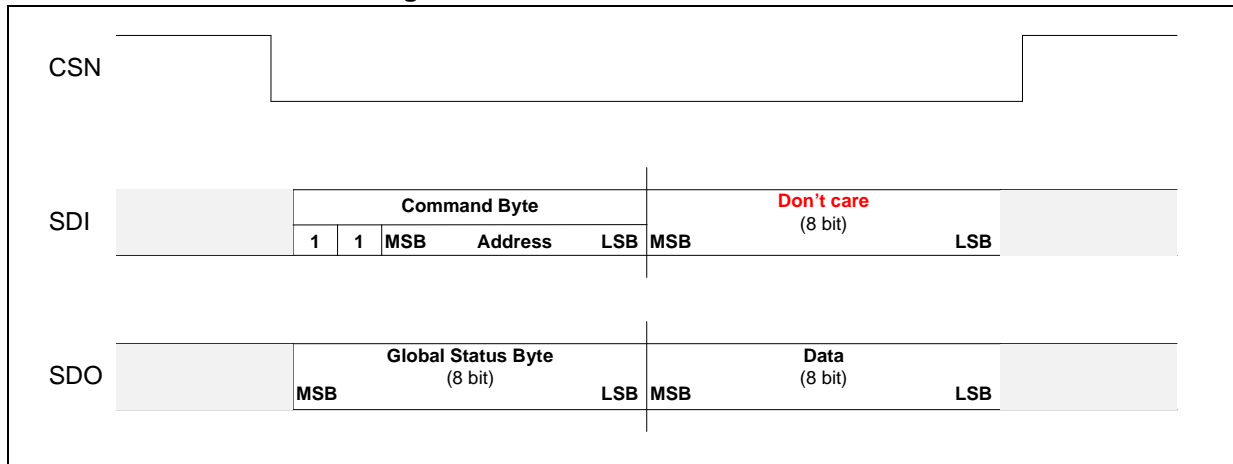
Read device information

Specific information can be read but not modified during this mode.

Incoming data are sampled on the rising edge of the serial clock (SCK), MSB first. The command byte allows to determine which information is read while the data byte is 'don't care'.

Outgoing data are shifted out MSB first on the falling edge of the CSN pin and others on the falling edge of the serial clock (SCK). The first byte corresponds to the Global Status byte and the second to the content of the addressed register.

Figure 26. SPI read device information



3.4 Address mapping

Table 10. RAM memory map

| Address | Name | Access | Content |
|---------|--------------------|------------|--|
| 00h | Reserved | Read/write | Reserved |
| 01h | Control register 1 | Read/write | Mux settings, WD period and retrigger |
| 02h | Control register 2 | Read/write | Spread spectrum settings, max input current and LED current settings |
| 03h | Control register 3 | Read/write | SW Limp Home, OTA/driver and converter delay control |
| 04h | Status register 1 | Read | Detailed status information |
| 05h | Status register 2 | Read | WD status, operation mode and LMode error |
| 3E | Trimming and test | Read | Trimming bus and test mode select |
| 3F | Configuration reg. | Read/write | WD retrigger bit |

Table 11. ROM memory map

| Address | Name | Access | Content |
|---------|----------------|-----------|---|
| 00h | ID header | Read only | 4300h (ASSP ST_SPI) |
| 01h | Version | Read only | 0100h |
| 02h | Product code 1 | Read only | 3100h (dec. 49) |
| 03h | Product code 2 | Read only | 5100h (ASCII 'Q') |
| 3Eh | SPI frame ID | Read only | 4200h (Watchdog available, 24 bit ST-SPI) |

3.5 Control registers (RAM)

Control registers 1

| | | | | | | | | | | | | | | | |
|----------|----|----|----|----|----|---|---|---|---|------------|--------|--------|-----------|---------|---|
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Reserved | | | | | | | | | | Mux[[1:0]] | Mux_En | En_Ntc | WD_Period | WD_trig | |

Address: 0x01h
Type: R/W
Reset: 0000 0000 0000 1110b

Bit [6:15] Reserved

Bit [5:4] Mux[1:0]:
 00 (default): the signal on the PWM pin is reflected on Mout pin
 01: the signal on the V_{LED} is reflected on Mout pin
 10: the signal on NTC is selected
 11: the signal on Lmode pin is selected

Bit [3] Mux_En:
 0: the Mout pin is inactive (tristate)
 1: the Mout pin is active (default)

Bit [2] En_Ntc:
 When set, the current fold back feature enabled in case of LED overtemperature conditions.
 This bit is ignored in case of any LIMP MODE and the LED temperature monitoring is activated (the NTC control is internal)

Bit [1] WD_Period:
 0: WD timeout = 100 ms
 1: WD timeout = 200 ms (default)

Bit [0] WD_trig:
 This bit must be toggled within the WD period to refresh the WD

Control registers 2

| | | | | | | | | | | | | | | | |
|-----------|----|----|-----------|----|---------|---------------|---|---|---|---------------|---|---|---|---|---|
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Fdev[2:0] | | | Fmod[1:0] | | Dith_En | Led_Curr[4:0] | | | | Max_Curr[4:0] | | | | | |

Address: 0x02h
Type: R/W
Reset: 0101 1110 0001 1111b

Bit [15:13] Fdev[2:0]: frequency deviation of the internal oscillator (see [Table 12](#))

Bit [12:11] Fmod[1:0]: frequency modulation of the internal oscillator (see [Table 13](#))

Bit [10] Dith_En: enable or disable random dither effect.
 If this bit is set Dithering is enabled;
 If the bit is reset, the dithering is disabled

Bit [9:5] Led_Curr[4:0]: these bits set the LED current.

The LED current is given by:

$$0.05 + (0.2 * \text{Led_Curr}[4:0]d) / 31) / (R_{\text{SENSE}}) \text{ [A] (typ)}$$

Where Led_Curr[4:0]d = decimal value of Led_Curr[4:0]

Bit [4:0] Max_Curr[4:0]: these bits set the maximum input current.

The internal current limiter voltage threshold is:

$$1 + (2.5 * \text{Max_Curr}[4:0]d) / 31 \text{ in [V] (typ)}$$

Considering the gain of the amplifier of 10, the current limitation is:

$$(1 + 2.5 * \text{Max_Curr}[4:0]d / 31) / (10 R_{\text{SHUNT}}) \text{ (typ);}$$

Where Max_Curr[4:0]d = decimal value of Max_Curr[4:0]

Table 12. Internal oscillator frequency deviation settings

| Fdev[2] | Fdev[1] | Fdev[0] | Frequency deviation |
|---------|---------|---------|---------------------|
| 0 | 0 | 0 | 0 % |
| 0 | 0 | 1 | 5 % |
| 0 | 1 | 0 | 10 % |
| 0 | 1 | 1 | 15 % |
| 1 | 0 | 0 | 20 % |
| 1 | 0 | 1 | 25 % |
| 1 | 1 | 0 | 30 % |

Table 13. Internal oscillator frequency modulation settings

| Fmod[1] | Fmod[0] | Frequency modulation |
|---------|---------|----------------------|
| 0 | 0 | 1.95 kHz |
| 0 | 1 | 3.9 kHz |
| 1 | 0 | 7.8 kHz |
| 1 | 1 | 15.6 kHz |

Control registers 3

| | | | | | | | | | | | | | | | |
|----------|----|----|-------|---------------|----|---|---|---------------|---|---|---|---|---|---|---|
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Reserved | | | Lh_Sw | Ctrl_Ota[3:0] | | | | Ctrl_Drv[3:0] | | | | | | | |

Address: 0x03h
Type: R/W
Reset: 0000 1000 0000 0000b

Bit [15:13] Reserved

Bit [12] Lh_Sw:

The device goes in Limp Home mode without WD supervision (V_{CC1} stays on) when the bit is set

Bit [11:8] Ctrl_Ota[3:0]: these bits set the delay between a rising edge of the PWM_L signal and a connection of the output of the operation transconductance amplifier.

The delay is given by $\text{Ctrl_Ota}[3:0]d * 3.3 \mu\text{s}$ (typ.)

Where Ctrl_Ota[3:0]d is the decimal value of Ctrl_Ota[3:0]

The default of these bits are loaded from the corresponding control bus

Bit [7:4] Ctrl_Drv[3:0]: these bits set the delay between a rising edge of the PWM_L signal and the activation of the converter

The delay is given by:

$\text{Ctrl_Drv}[3:0]d * 1.67 \mu\text{s}$ (typ.)

Where Ctrl_Drv[3:0]d is the decimal value of Ctrl_Drv[3:0]

The default of these bits are loaded from the corresponding control bus

Bit [3:0] Ctrl_Sw[3]: these bits set the delay between the falling edge of the PWM_L signal and the turn off of the dimming mosfet M2.

The delay is given by:

$\text{Ctrl_Sw}[3:0]d * 1.67 \mu\text{s}$ (typ.)

Where Ctrl_Sw[3:0]d is the decimal value of Ctrl_Sw[3:0]

The default of these bits are loaded from the corresponding control bus.

3.6 Status registers

Status registers 1

| | | | | | | | | | | | | | | | |
|----------|----|----|------------------|-------|------------------|--------------------|--------|--------|----------|--------------------|------------|---------|---------|------------|---------|
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Reserved | | | Lmode_Err | Vs_Ov | Vs_Uv | Led_Temp_War | Led_Oc | Led_Ov | Vcc1_Off | Vcc1_Fail | Vcc1_Uv_To | Vcc1_Ot | Vcc1_Sc | SDI_stuck@ | WD_fail |
| — | | | R ⁽¹⁾ | R | R ⁽¹⁾ | R/C ⁽²⁾ | | | R | R/C ⁽²⁾ | | | | | |

1. "Read only", real time bit.
2. These bits are latched until a "Read and Clear" access.

Address: 0x04h

Type: R/C

Bit [15:13] Reserved

Bit [12] Lmode_Err: this bit is set if a mismatch between the signal on LMODE pin and VLED pin is detected.

Bit [11] Vs_Ov: is set if an overvoltage event at the supply line is detected

Bit [10] Vs_Uv: is set if an under voltage event at the supply line is detected

Bit [9] Led_Temp_Warn: temperature warning for the LED

Bit [8] Led_Oc: Is set if an over current event across the LED chain is detected

Bit [7] Led_Ov: is set if an overvoltage event across the LED chain is detected

Bit [6] Vcc1_Off: when set, this bit indicated that V_{CC1} is off

Bit [5] Vcc1_Fail

Indicates that:

V_{CC1} is below V_{CC1_FAIL} threshold for typ. 2 μ s in active mode

V_{CC1} is below V_{CC1_FAIL} threshold for more than 4 ms typ. during start up

Bit [4] Vcc1_Uv_To: this bit is set in active mode if V_{CC1} is below the reset threshold for more than typ. 2 ms

Bit [3] Vcc1_Ot: set if an overtemperature condition has been detected on V_{CC1}

Bit [2] Vcc1_Sc: indicates a short circuit on V_{CC1} .

This bit is set if V_{CC1} stays below the V_{CC1_FAIL} threshold 4 ms (typ.) after the power on reset or below the reset threshold 100 ms after the POR (Power On Reset)

Bit [1] SDI_stuck@

Bit [0] WD_fail

Status registers 2

| | | | | | | | | | | | | | | | |
|----------|----|----|----|----|----|---|------------|------------------|-------|------------|------------------|----------|------------------|---|---|
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Reserved | | | | | | | Led_Ov_Rec | Ext_Vcc | PWM_L | Standalone | LHM | Lh_Sw_St | WD_Status[2:0] | | |
| — | | | | | | | R | R ⁽¹⁾ | | R | R ⁽¹⁾ | R | R ⁽²⁾ | | |

1. "Read only", real time bit.
2. "Read only" bit. These bits are cleared by a WD re-trigger.

Address: 0x05h

Type: R

Bit [15:9] Reserved

Bit [8] Led_Ov_Rec

Once this bit is set, the device will make a single trial to recover from an LED overvoltage.

Bit [7] Ext_Vcc: this bit reflects the signal on the Ext_Vcc pin,

Bit [6] PWM_L: this bit reflects the signal on the PWM_L pin

Bit [5] Standalone: this bit is set if the device operates in standalone mode, without microcontroller

Bit [4] LHM: reflects the level at LHM pin

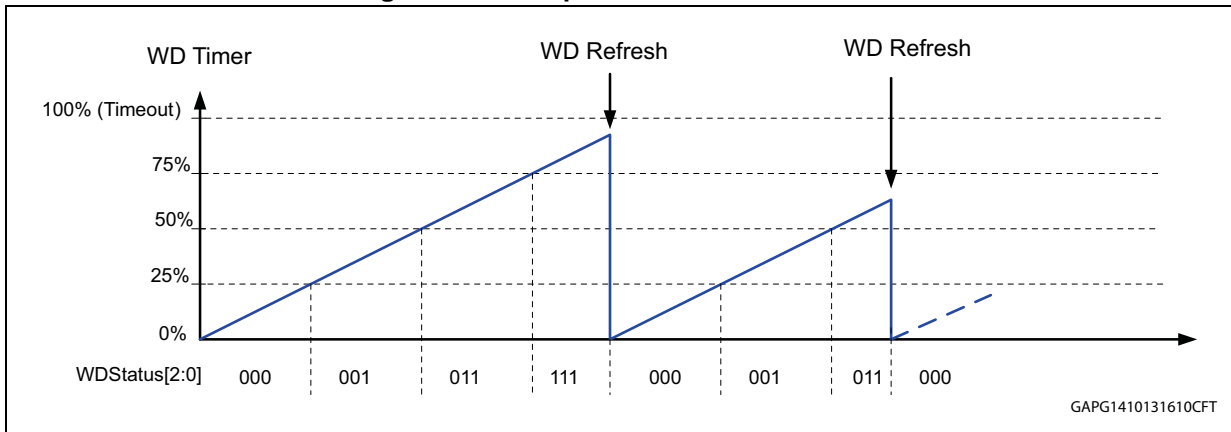
Bit [3] Lh_Sw_St: is set if the software limp home mode is activated

Bit [2:0] WD_status[2:0]: these bits indicate the status of the watchdog timer (see [Table 14](#) and see [Figure 27](#))

Table 14. Watchdog timer status

| WD_Status[1] | WD_Status[1] | WD_Status[0] | WD timer status |
|--------------|--------------|--------------|------------------|
| 0 | 0 | 0 | [0...25 %[|
| 0 | 0 | 1 | [25 % ... 50 %[|
| 0 | 1 | 1 | [50 % ... 75 %[|
| 1 | 1 | 1 | [75 % ... 100 %[|

Figure 27. Principle of the WD_Status bits



Trimming and test register

| | | | | | | | | | | | | | | | |
|---------|----|----|----|----|----|---|---|---------------|---|---|---|---|---|---|---|
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TM[5:0] | | | | | | | | Trim_Bus[9:0] | | | | | | | |
| R/W | | | | | | | | R | | | | | | | |

Address: 0x3Eh

Type: R/W

Reset: 0000 0000 0000 0000b

Bit [15:10] TM[5:0]: test mode selection (refer to the UQ49 test controller)

Bit [9:0] Trim_Bus[9:0]: copy of the data stored in the trimming fuse cells

Configuration register

| | | | | | | | | | | | | | | | |
|----------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---------|
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Reserved | | | | | | | | | | | | | | | WD_Trig |
| — | | | | | | | | | | | | | | | R/W |

Address: 0x3Fh

Type: R/W

Reset: 0000 0000 0000 0000b

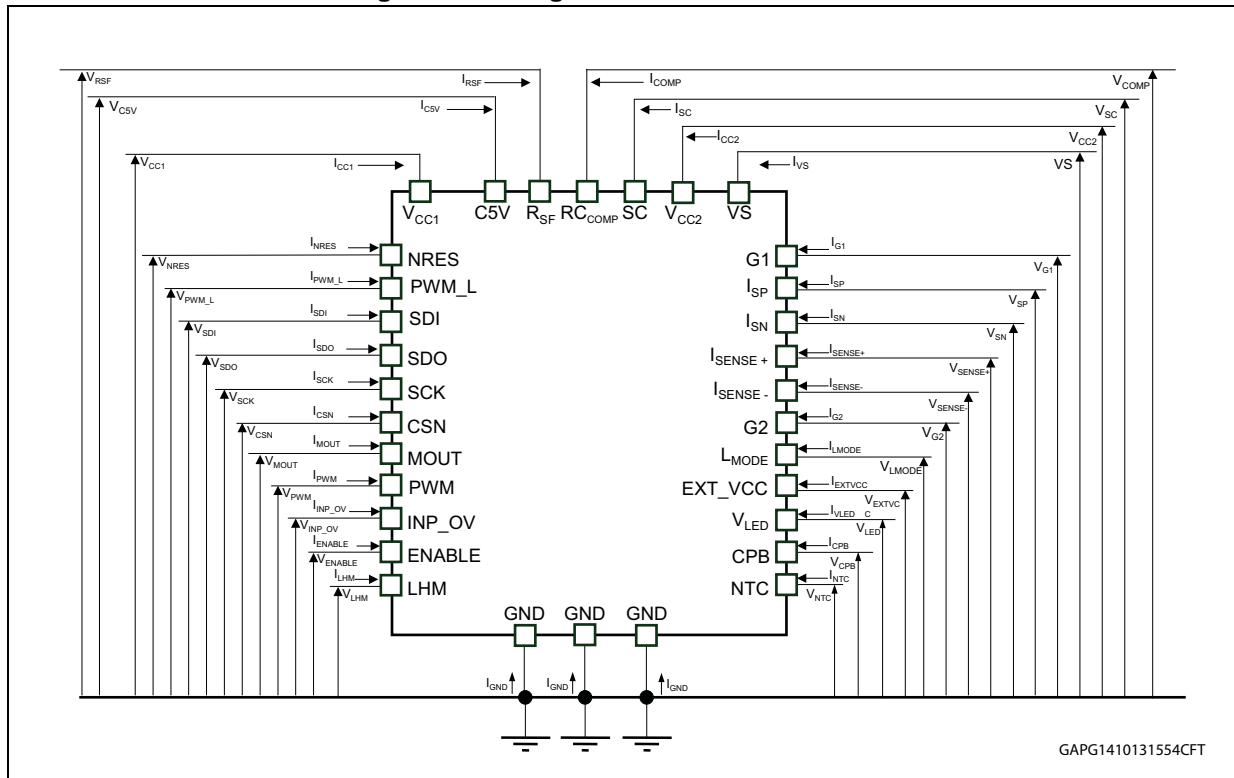
Bit [15:1] Reserved

Bit [0] WD_Trig: this bit must be toggled within the WD period to refresh the WD.

Note that this bit is copied in the Control register 1, bit 0

4 Electrical specifications

Figure 28. Voltage and current conventions



4.1 Absolute maximum ratings

Maximum ratings are absolute ratings; exceeding any one of these values may cause permanent damage to the integrated circuit.

Table 15. Absolute maximum ratings

| Symbol | Parameter | Value | Unit |
|---------------------|---|----------------------------|------|
| V _S | DC operating supply voltage | 5.6 / 24 | V |
| V _{S_TR} | Transient operating supply voltage (T < 400 ms) | -0.3 / 40 | V |
| V _{SDI} | SPI data input voltage range | -0.3 / +5.3 | V |
| V _{SDO} | SPI data output voltage range | -0.3 / +5.3 | V |
| V _{SCK} | SPI clock voltage range | -0.3 / +5.3 | V |
| V _{CSN} | SPI chip select not voltage range | -0.3 / +5.3 | V |
| V _{NRES} | Reset output pin voltage range | -0.3 ÷ V _S +0.3 | V |
| V _{CC1} | Regulator1 supply voltage output | -0.3 / + 5.5 | V |
| V _{CC2} | Regulator 2 supply voltage output | -0.3 / + 10.5 | V |
| V _{ENABLE} | Enable input pin voltage range | -0.3 ÷ V _S +0.3 | V |

Table 15. Absolute maximum ratings (continued)

| Symbol | Parameter | Value | Unit |
|----------------------|--|---|------|
| V _{SC} | Slope compensation input voltage range | -0.3 / + 5.3 | V |
| V _{LHM} | Limp home mode input pin voltage range | -0.3 ÷ V _S +0.3 | V |
| V _{PWM} | Input L.F. PWM voltage range | -0.3 ÷ V _S +0.3 | V |
| V _{PWM_L} | Logic level L.F. PWM input voltage range | -0.3 / +5.3 | V |
| V _{MOUT} | Multiplexed data output pin voltage range | -0.3 / +5.3 | V |
| V _{G1} | Driver 1 output voltage range | -0.3 / (V _{CC2} + 0.3) | V |
| V _{G2} | Driver 2 gate output voltage range | -0.3 / min (V _{CPB} + 0.3, 68) | V |
| V _{EXT_VCC} | External VCC voltage range | -0.3 / 5.3 | V |
| V _{CPB} | External capacitor voltage range | V _{ISENSE+} - 0.8 V / min (V _{ISENSE+} + 16 V, 68 V) | V |
| V _{ISENSE+} | Positive sensing res. voltage range | -0.3 / 55 | V |
| V _{ISENSE-} | Negative sensing res. voltage range | V _{ISENSE+} - 5 V / V _{ISENSE+} + 0.3 V | V |
| V _{SP} | Sensing positive shunt res voltage range | -0.3 / +5.3 | V |
| V _{SN} | Sensing negative shunt res voltage range | -0.3 / +5.3 | V |
| V _{INP_OV} | overvoltage input pin voltage range | -0.3 ÷ V _S +0.3 | V |
| V _{RSF} | External set frequency resistor voltage range | -0.3 / 5.5 | V |
| V _{C5V} | C5V ext capacitor voltage range | -0.3 / 5.5 | V |
| V _{RC_COMP} | External RC network input pin voltage range | -0.3 / 5.5 | V |
| V _{NTC} | External NTC resistor input voltage range | -0.3 / 5.5 | V |
| V _{LED} | LED chain drop voltage detection input range | -0.3 / + 65 | V |
| V _{LMODE} | LED Mode switch voltage range | -0.3 / +5.3 | V |
| V _{ESD} | Electrostatic discharge (HBM R = 1.5 kΩ; C = 100 pF) | ± 2 | kV |
| V _{ESD} | CDM model all pin | 500 | V |
| V _{ESD} | CDM for corner pin | 750 | V |
| T _j | Junction operating temperature | -40 to 150 | °C |
| T _{stg} | Storage temperature | -55 to 150 | °C |

Table 16. Thermal data

| Symbol | Parameter | Value | Unit |
|-----------------------|--|-------|------|
| R _{Thj-case} | Thermal resistance junction to case | 27 | °C/W |
| R _{Thj-amb} | Thermal resistance junction to ambient | 90 | °C/W |

5 Electrical characteristics

Values specified in this section are for $5.6\text{ V} \leq V_S \leq 24\text{ V}$; $-40\text{ }^\circ\text{C} \leq T_j \leq 150\text{ }^\circ\text{C}$, unless otherwise specified

Table 17. VS and V_{CC1} pin characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Unit |
|-----------------|---|---|-----|-----|------|---------------|
| V_S | Operative battery voltage | | 5.6 | | 24 | V |
| I_S | Supply current consumption in continuous mode (L.F. PWM = 100 %) | $V_S = 13.5\text{ V}$; $F_{REQ} = 300\text{ kHz}$; $I_{CC1} = I_{CC2} = I_{C5V} = 0$ | | | 20 | mA |
| I_{S_STBY} | Supply current consumption in stand by mode | Enable = Low; LHM,CSN,PWM, INP_OV = open; $V_{NRES} \leq 5.5\text{ V}$; $V_S = 13.5\text{ V}$; $T_j = 25\text{ }^\circ\text{C}$ | | | 12 | μA |
| V_{SMIN} | Minimum V_S required for reaching V_{CC1} nominal value | V_S ramp up | 4.8 | 5.2 | 5.6 | V |
| V_{SMIN_HYS} | V_{SMIN} hysteresis | V_S ramp down | | 0.2 | | V |
| t_{VSM} | V_{SMIN} filtering time | | 13 | 16 | 23 | μs |
| V_{CC1} | D.C. logic supply output voltage | $1 < -I_{CC1} < 10\text{ mA}$ | 4.9 | 5 | 5.1 | V |
| $-I_{CC1}$ | Output current capability | $V_S = 13.5\text{ V}$; $V_{CC1} = V_{CC1_1mA} - 0.1\text{ V}^{(1)}$ | 50 | | | mA |
| V_{CC1_DROP} | Min voltage drop of V_{CC1} respect to V_S ; $V_{CC1_DROP} = \min(V_S - V_{CC1})$ | $-I_{CC1} = 10\text{ mA}$ | | | 500 | mV |
| V_{CC1_LINE} | Line regulation voltage | $-I_{CC1} = 10\text{ mA}$; $V_{CC1@5.6} - V_{CC1@24}$ | | | 5 | mV |
| V_{CC1_LOAD} | Load regulation voltage | $-I_{CC1} = 1\text{ to }10\text{ mA}$; $V_S = 13.5\text{ V}$ | | | 10 | mV |
| V_{CC1_FAIL} | V_{CC1} fail detection threshold ⁽²⁾ | $V_S \geq V_{SMIN}$; V_{CC1} rising | 2.4 | 2.6 | 2.8 | V |
| | | $V_S \geq V_{SMIN}$; V_{CC1} falling | 1.9 | 2.1 | 2.3 | V |
| $t_{LMODERR}$ | Filtering time for LMODE error | | 13 | 16 | 23 | μs |
| t_{OC} | Filtering time for LED overcurrent | | 13 | 16 | 23 | μs |
| t_{LEDOV} | Filtering time for LED overvoltage | | 12 | 15 | 22 | μs |
| t_{WD1} | 1st watchdog time-out period | | 85 | 100 | 135 | ms |
| t_{WD2} | 2nd watchdog time-out period | | 170 | 200 | 275 | ms |
| t_{V1F} | Internal filtering time for v_{cc1} fail detection | $V_S \geq V_{SMIN}$ | 1.7 | 2 | 2.75 | μs |
| t_{SHTV1A} | Time to detect a short on V1 regulator at turn-on | $V_S \geq V_{SMIN}$; $V_{CC1} < V_{CC1_FAIL}$; $t \geq t_{SHTV1A}$ | | 4 | | ms |
| t_{SHTV1B} | Time to detect a short on V1 regulator at turn-on | $V_S \geq V_{SMIN}$; $V_{CC1_FAIL} \leq V_{CC1} \leq V_{CC1_TH}$; $t \geq t_{SHTV1B}$ | | 100 | | ms |

Table 17. VS and V_{CC1} pin characteristics (continued)

| Symbol | Parameter | Test condition | Min | Typ | Max | Unit |
|-------------------------|---|---|------|-----|------|------|
| CV _{CC1} | Load capacitance | A good quality (Low ESR) capacitor is recommended | 1 | 10 | | μF |
| V _{CC1_OT} | Regulator 1 over temperature detection level | | 150 | 175 | 190 | °C |
| V _{CC1_OT_HYS} | Hysteresis | | 20 | 25 | 30 | °C |
| t _{V1OT} | Filtering time for regulator 1 over temperature detection | | 0.75 | 1 | 1.55 | ms |

1. V_{CC1_1mA} is V_{CC1} at I_{LOAD} = 1 mA; V_S = 13.5 V.
2. Minimum V_{CC1} voltage for keep RAM data.

Table 18. V_{CC2} and C5V pin characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|-------------------------|--|---|------|-----|------|-------|
| V _{CC2} | D.C. logic supply output voltage | $1 \leq -I_{CC2} \leq 10 \text{ mA}$; V _S = 13.5 V; V _{PWM_L} = 0 | 9.5 | 10 | 10.5 | V |
| -I _{CC2} | Output current capability | V _S = 13.5 V; V _{CC2} = V _{CC2_1mA} - 0.1 V ⁽¹⁾ ; V _{PWM_L} = 0 | 20 | | | mA |
| V _{CC2_DROP} | Drop voltage to V _S : V _{CC2_DROP} = (V _S - V _{CC2}) | -I _{CC2} = 1 mA; V _{CC2} = 9.5 V; V _{PWM_L} = 0 | | | 100 | mV |
| -I _{CC2_SHT} | Short output current limitation | $0 \leq V_{CC2} \leq V_{CC2_1mA}$; V _S = 13.5 V; V _{PWM_L} = 0 | | | 100 | mA |
| CV _{CC2} | Load capacitance | A good quality (Low ESR) capacitor is recommended for correct managing gate peaks current during switching On and OFF of G1 | 10 | | | μF |
| V _{CC2_OT} | Regulator 2 over temperature detection level | | 150 | 175 | 190 | °C |
| V _{CC2_OT_HYS} | Over temperature detection level hysteresis | | 20 | 25 | 30 | °C |
| V _{C5V} | Internal 5 V output voltage | $0 \leq -I_{C5V} \leq 2.5 \text{ mA}$ | 4.75 | 5 | 5.25 | V |
| -I _{C5V} | 5 V output current | V _{C5V} = V _{C5V_1mA} ⁽²⁾ - 0.1 | 2.5 | | | mA |
| -I _{C5V_SHT} | Short output current limitation | $0 \leq V_{C5V} \leq V_{C5V_1mA}$ ⁽³⁾ (pulsed s.c. no continuous short) | | | 50 | mA |
| C _{5V} | Load capacitance See Figure 34 | | 1 | | | μF |

1. V_{CC2_1mA} is the value of V_{CC2} at I load = 1 mA, V_S = 13.5 V; T_j = 25 °C.
2. V_{C5V_1mA} is the value of V_{C5V} at external I_{C5V} load = 1 mA, V_S = 13.5 V; T_j = 25 °C.
3. V_{C5V_1mA} is the value of V_{C5V} at external I_{C5V} load = 1 mA, V_S = 13.5 V; T_j = 25 °C.

Table 19. NRES and L_{MODE} pin characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Unit |
|----------------------|---|--|-----|-----|-----|------|
| V _{CC1_TH} | Reset intervention threshold | | 4.6 | 4.7 | 4.8 | V |
| T _{RR} | V _{CC1} reset filtering time | V _{CC1} < V _{CC1_TH} | 13 | 16 | 23 | µs |
| t _{FS} | V _{CC1} reset time-out for fail safe detection | V _S ≥ V _{SMIN} ; V _{CC1} < V _{CC1_TH} ; t ≥ t _{FS} | 1.6 | 2 | 2.9 | ms |
| T _{RD} | Reset delay time | V _{CC1} ≥ V _{CC1_TH} | 1.6 | 2 | 2.9 | ms |
| I _{NRES} | High state reset sink current | V _{NRES} = V _S ; NRES active | 0.5 | 1.7 | 3.5 | mA |
| I _{NRES} | High state reset leakage current | V _{NRES} = V _S ; NRES inactive | | | 300 | µA |
| V _{NRES_L} | Reset I/O low state level | V _{CC1} ≤ V _{CC1_TH} ; I _{NRES} = 1 mA | | | 0.5 | V |
| V _{LMODE_H} | Led mode switch high state input | | 4 | | | V |
| V _{LMODE_L} | Led mode switch low state input | | | | 1 | V |
| -I _{LMODE} | Internal pull up current source | V _{LMODE} = 0 | 10 | 18 | 25 | µA |

Table 20. G1 driver 1 pin characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Unit |
|-------------------|-----------------------------|--|-----|-----|------------------|------|
| V _{G1_H} | Gate1 high level | | 5 | | V _{CC2} | V |
| V _{G1_L} | Gate1 low level | | | | 0.5 | V |
| tr _{G1} | Gate1 charging rise time | CG = 4.7 nF; V _{GS1} rising from 10 % to 90 %; V _S ≥ 10 V | | | 40 | ns |
| tf _{G1} | Gate1 discharging fall time | CG = 4.7 nF; V _{GS1} falling from 90 % to 10 %; V _S ≥ 10 V | | | 40 | ns |

Table 21. G2 pin characteristics (driver2)

| Symbol | Parameter | Test condition | Min | Typ | Max | Unit |
|--------------------|---|---|-----------------------------|-----|-----------------------------|------|
| V _{G2_H} | High state output V _{G2} voltage | PWM_L = High; V(I _{SENSE+}) = 30 V | V(I _{SENSE+}) +10 | | V(I _{SENSE+}) +14 | V |
| V _{G2_L} | Low state output voltage V _{G2} | PWM_L = Low; V(I _{SENSE+}) = 30 V | | | 0.05 | V |
| -I _{G2_H} | Gate 2 high state output current | PWM_L = High; V _{GS_M2} = 6 V ⁽¹⁾ ; C _{GS_M2} = 1 nF; V(I _{SENSE+}) = 30 V | 200 | | | µA |
| I _{G2_L} | Gate 2 low state output current | PWM_L = Low; V _{GS_M2} = 6 V ⁽²⁾ ; C _{GS_M2} = 1 nF; V(I _{SENSE+}) = 30 V | 200 | | | µA |

1. I_{G2_H} current is measured when the voltage across gate and source of Mosfet M2 (V_{GS_M2}) reaches a value of 6 V during its rising transient.
2. I_{G2_L} current is measured when the voltage across gate and source of Mosfet M2 (V_{GS_M2}) reaches a value of 6 V during its falling transient.

Table 22. Converter oscillator and R_{SF} pin characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Unit |
|---------------------------------------|---|---|----------------------|------|------|------|
| V _{RSF} | Voltage at pin R _{SF} | I _{RSF} = 42 μA | 1.12 | 1.21 | 1.25 | V |
| F _O | DC-DC converter frequency range | See Figure 12 | 100 | | 520 | kHz |
| F _{O_S} | Oscillator frequency spread at 125 kHz | I _{RSF} = 17 μA (F _O ≈ 125 kHz) | 100 | 125 | 150 | kHz |
| F _{O_S} | Oscillator frequency spread at 300 kHz | I _{RSF} = 42 μA (F _O ≈ 300 kHz) | 240 | 300 | 360 | kHz |
| F _{O_S} | Oscillator frequency spread at 470 kHz | I _{RSF} = 67 μA (F _O ≈ 470 kHz) | 420 | 470 | 520 | kHz |
| Duty cycle max | DC-DC converter max duty cycle limit | | | 90 | | % |
| Duty cycle min | DC-DC converter min duty cycle limit | | | 10 | | % |
| F _{MOD} | Modulation frequency of the internal oscillator | See Section 3.5: Control registers (RAM) F _{MOD} [0:1] | 1.95, 3.9, 7.8, 15.6 | | | kHz |
| D% = ΔF ₀ / F ₀ | Frequency deviation factor | See Section 3.5: Control registers (RAM) F _{DEV} [0:2] | 0 to ±35 (step ±5 %) | | | % |

Table 23. PWM_L, PWM, MOUT pin characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Unit |
|-----------------------|--|-----------------------------|-----|-----|-----|------|
| TON _{PWM_L} | Minimum PWM_L on time | Q _G = 9 nC | 100 | | | μs |
| PWM_L _{LOW} | Low level PWM_L input voltage | | | | 1 | V |
| PWM_L _{HIGH} | High level PWM_L input voltage | | 4 | | | V |
| I _{PWM_L_PD} | Pull down current source | | 20 | 28 | 35 | μA |
| PWM _{LOW} | Low level PWM input voltage | | | | 1 | V |
| PWM _{HIGH} | High level PWM input voltage | | 4 | | | V |
| R _{PWM_PD} | Pull Down resistor | | 50 | 230 | 500 | kΩ |
| V _{MOUT_H} | High state output voltage (digital mode) | -I _{MOUT} = 0.1 mA | 4 | | | V |
| V _{MOUT_L} | Low state output voltage (digital mode) | I _{MOUT} = 0.1 mA | | | 1 | V |
| Z _{MOUT} | Analogue mode output impedance | | | 10 | | kΩ |

Table 24. I_{SENSE+}, I_{SENSE-} pin, and O.T.A. characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|---|--|----------------|----------------------|-----|-----|-------|
| V _{ISENSE+} V _{ISENSE-} | Common mode input range | | V _S - 0.3 | | 49 | V |
| (V _{ISENSE+} - V _{ISENSE-}) | Operative differential input voltage range | | -1 | | 0.3 | V |

Table 24. I_{SENSE+}, I_{SENSE-} pin, and O.T.A. characteristics (continued)

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|--|---|--|--------------------------|---|--------------------------|-------|
| (V _{ISENSE+} - V _{ISENSE-}) _{TH} | LED over current protection threshold | V(I _{SENSE+}) = 25 V; V _{LREF} = V _{LREF_16} ; V _{RCCOMP} = 2 V | V _{LREF} + 0.03 | V _{LREF} + 0.08 | V _{LREF} + 0.14 | V |
| I _{SENSE_CD} | Current consumption from I _{SENSE+} (LED_OV) | V _{SENSE+} = V _{SENSE-} = 25 V | 3 | 5 | 10 | mA |
| V _{SENSE_MAX_1} | Threshold at pin I _{SENSE+} for overvoltage protection (activation) | | 49.5 | 52 | 54 | V |
| V _{SENSE_MAX_2} | Threshold at pin I _{SENSE+} for overvoltage protection (de-activation) | | 25 | 33 | 35 | V |
| V _{OFFS} | OTA input offset voltage | V _{LREF} = 0 V; V(I _{SENSE+}) = 25 V; V _{RCCOMP} = 2 V | -10 | | 10 | mV |
| I _{OFFS} | OTA input offset current | V(I _{SENSE+}) = 25 V; V _{RCCOMP} = 2 V | | | 10 | μA |
| G _M | Transconductance gain | V(I _{SENSE+}) = 25 V; V _{RCCOMP} = 2 V | 0.95 | 1.2 | | mS |
| -I _{COMP} | Sourced output current | V _{LREF} = V _{LREF_16} ; (V _{ISENSE+} - V _{ISENSE-}) = 0 | 50 | 175 | | μA |
| I _{COMP} | Sunk output current | V _{LREF} = V _{LREF_16} ; (V _{ISENSE+} - V _{ISENSE-}) = 300 mV | 50 | 175 | | μA |
| | | V _{LREF} = V _{LREF_16} ; (V _{ISENSE+} - V _{ISENSE-}) = 1 V | 100 | 300 | | |
| V _{COMP} | Output voltage range | | 0 | | 3.5 | V |
| V _{LREF_16} | Default internal voltage reference for constant LED current regulation | Internal LED current register = 16d; V _{NTC} = 5 V; V _{ISENSE+} = 25 V | 138 | 150 | 162 | mV |
| V _{LREF} | Internal voltage reference range-for setting output LED current ⁽¹⁾ | V _{NTC} = 5 V | | (8 + N) / 24 * V _{LREF_16} (2) | | mV |
| V _{LREF_NTC} | Max internal V _{LREF} reduction caused by NTC intervention (thermal LED current reduction) | V _{NTC} = 0 V | | 0.5 * V _{LREF} | | mV |
| V _{LREF-STEP} | Internal voltage reference step | | | 4 / 3 * (V _{LREF_16} / 31) | | mV |
| I _{SP} , I _{SN} pin characteristics | | | | | | |
| V _{SP} , V _{SN} | Shunt resistor input voltage range | | -0.3 | | 5 | V |

Table 24. I_{SENSE+} , I_{SENSE-} pin, and O.T.A. characteristics (continued)

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|------------------------|---|--|-------------------------|--------------------------------|--------------|-------|
| $V_{SP-V_{SN}}$ | Differential input voltage range | | -0.3 | | 0.5 | V |
| G_{LA_CPK} | Gain of internal linear amplifier | $V_{SP} = 100\text{ mV}$; $V_{SN} = 0\text{ V}$; Pin SC floating | 8 | 9.8 | 12 | |
| V_{LA_OFFS} | Linear amplifier output offset voltage | $V_{SP} = V_{SN} = 0$ | | 150 | 350 | mV |
| V_{CL_31} | Default internal reference for the current limiter ⁽³⁾ | Internal C.L. register = 31 | | 3.5 | | V |
| $(V_{SP-V_{SN}})_{TH}$ | Differential threshold voltage for activate max input current prot. | Internal C.L. register = 31; $V_{SC} = 5\text{ V}$ | 300 | 350 | 400 | mV |
| V_{CL} | Internal C.L. voltage reference range | | 0.279 * V_{CL_31} | | V_{CL_31} | V |
| V_{CL_STEP} | Internal C.L. voltage reference step | | | (0.721 * $V_{CL_31} / 31)$ | | V |

1. Writing into 5 bit LED Current Register via SPI.
2. N is the number corresponding to the 5 bits of LED_CURR control register.
3. Settable by loading the 5 bit C.L. Register via SPI.

Table 25. SC pin characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|----------------|----------------------------|----------------|-----|-----|------|------------|
| V_{SC_low} | Min ramp voltage at pin SC | $I_{SC} = 0$ | | 0.2 | 0.45 | V |
| V_{SC_HIGH} | Max ramp voltage at pin SC | $I_{SC} = 0$ | 1.4 | 2 | 2.6 | V |
| R_{SC} | Ext. resistor range | | 10 | | 1000 | k Ω |

Table 26. V_{LED} pin characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|----------------|--|--------------------------|-------|-----|---------|------------|
| V_{LED} | Operative input voltage range for OV detection | $L_{MODE} = \text{low}$ | 0 | | 5 | V |
| | | $L_{MODE} = \text{high}$ | V_S | | V_S+5 | |
| R_{VLED_PD} | Pull down resistor | | 0.4 | 0.8 | 1.2 | m Ω |
| OV_TH1 | LED overvoltage threshold 1 boost application | $L_{MODE} = \text{low}$ | 3.4 | 3.5 | 3.6 | V |
| OV_TH2 | LED overvoltage threshold 2 boost application | $L_{MODE} = \text{low}$ | 2.3 | 2.5 | 2.7 | V |

Table 26. V_{LED} pin characteristics (continued)

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|-----------|--|--------------------------|-------------|--------------|-------------|-------|
| OV_TH1_VS | LED overvoltage threshold 1 buck-boost application | $L_{MODE} = \text{high}$ | $V_S + 3.2$ | $V_S + 3.55$ | $V_S + 3.8$ | V |
| OV_TH2_VS | LED overvoltage threshold 2 buck-boost application | $L_{MODE} = \text{high}$ | $V_S + 2.2$ | $V_S + 2.45$ | $V_S + 2.8$ | V |

Table 27. INP_OV pin characteristics (input overvoltage shut down)

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|--------------------|--|-----------------------------|-----|-----|-----|---------------|
| V_{INP_OV} | Operative input overvoltage range | | 0 | | 5 | V |
| $-I_{INP_OV}$ | Pull UP current source at input INP_OV | $V_{INP_OV} = 0 \text{ V}$ | 10 | 18 | 25 | μA |
| $V_{INP_OV_TH1}$ | Internal voltage reference 1 | | 3.4 | 3.6 | 3.7 | V |
| $V_{INP_OV_TH2}$ | Internal voltage reference 2 | | 2.7 | 2.9 | 3.1 | V |

Table 28. NTC pin characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|----------------|--|-------------------------|------|------|------|---------------|
| V_{NTC} | Operative NTC voltage range | | 0 | | 5 | V |
| I_{NTC} | Pull down current source | $V_{NTC} = 5 \text{ V}$ | 5 | 10 | 15 | μA |
| V_{NTC_TH1} | Reference for current LED thermal regulation, temp ramp up | LED temp ramp up | 1.13 | 1.2 | 1.27 | V |
| V_{NTC_TH2} | Reference for current LED thermal regulation, temp ramp down | LED temp ramp down | 1.38 | 1.45 | 1.52 | V |

Table 29. ENABLE, LHM pin characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|------------------|-------------------------------------|----------------|-----|-----|-----|---------------|
| V_{ENABLE_L} | Low level ENABLE input voltage | | | | 1 | V |
| V_{ENABLE_H} | High level ENABLE input voltage | | 4 | | | V |
| R_{ENABLE_PD} | Enable pull down resistor | | 50 | 250 | 500 | k Ω |
| V_{LHM_L} | Low level limp home mode input pin | | | | 1 | V |
| V_{LHM_H} | High level limp home mode input pin | | 4 | | | V |
| I_{LHM_PU} | Limp home pin pull up current | $V_{HLM} = 0$ | 10 | 18 | 25 | μA |

Table 30. Power on reset

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|---------|-----------------------------------|--|-----|-----|-----|-------|
| POR_TH1 | Internal power on reset threshold | V_{C5V} rising; $V_S = 13.5 \text{ V}$; $C5V = 10 \mu\text{F}$ | 3.2 | 3.7 | 4.2 | V |
| POR_TH2 | Internal power on reset threshold | V_{C5V} falling; $V_S = 13.5 \text{ V}$; $C5V = 10 \mu\text{F}$ | 2.7 | 3.4 | 3.7 | V |

Table 31. Watchdog and timers parameters

| Symbol | Parameter | Test condition | Min | Typ | Max | Units |
|---------------|-------------------------|----------------|-----|---------------------------|-----|-------|
| t_{WDTO} | Watchdog timeout window | | | 100 or 200 ⁽¹⁾ | | ms |
| t_{DStart} | Start time window | | | 5 | | ms |
| $t_{EnRecov}$ | | | | 5 | | ms |

1. Selectable by SPI command.

6 SPI electrical characteristics

6.1 DC characteristics

The voltages are referred to ground and currents are assumed positive, when the current flows into the pin. $6\text{ V} \leq V_S \leq 24\text{ V}$; all outputs open; $T_j = -40\text{ }^\circ\text{C}$ to $150\text{ }^\circ\text{C}$, unless otherwise specified.

Table 32. SPI DC characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Unit |
|-----------------------------|------------------------------|---|------------------|-----|------------------|---------------|
| Inputs: CSN, CLK, DI | | | | | | |
| V_{IL} | Input voltage low level | $V_S = 13.5\text{ V}$ | | | 0.3 V_{C5V} | V |
| V_{IH} | Input voltage high level | $V_S = 13.5\text{ V}$ | 0.7 V_{C5V} | | | V |
| V_{IHYS} | Input hysteresis | $V_S = 13.5\text{ V}$ | 500 | | | mV |
| $I_{CSN\text{ in}}$ | CSN pull-up current source | $V_S = 13.5\text{ V}$ | 10 | 18 | 25 | μA |
| $I_{CLK\text{ in}}$ | CLK pull-down current source | $V_S = 13.5\text{ V}$ | 20 | 25 | 35 | μA |
| $I_{DI\text{ in}}$ | DI pull-down current source | $V_S = 13.5\text{ V}$ | 20 | 25 | 35 | μA |
| Output: DO | | | | | | |
| V_{OL} | Output voltage low level | $I_{OL} = 5\text{ mA};$ $V_S = 13.5\text{ V}$ | | | 0.3 V_{C5V} | V |
| V_{OH} | Output voltage high level | $I_{OH} = -5\text{ mA};$ $V_S = 13.5\text{ V}$ | 0.7 V_{C5V} | | | V |

6.2 AC characteristics

The voltages are referred to ground and currents are assumed positive, when the current flows into the pin. $6\text{ V} \leq V_S \leq 24\text{ V}$; all outputs open; $T_j = -40\text{ }^\circ\text{C}$ to $150\text{ }^\circ\text{C}$, unless otherwise specified.

Table 33. SPI AC characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Unit |
|-----------------|----------------------------------|----------------|-----|-----|-----|------|
| $C_{OUT}^{(1)}$ | Output capacitance (DO) | | — | — | 10 | pF |
| $C_{IN}^{(1)}$ | Input capacitance (DI, CSN, CLK) | | — | — | 10 | pF |

1. Value of input capacity is not measured in production test. Parameter guaranteed by design.

6.3 Dynamic characteristics

The voltages are referred to ground and currents are assumed positive, when the current flows into the pin. $6\text{ V} \leq V_S \leq 24\text{ V}$; all outputs open; $T_j = -40\text{ }^\circ\text{C}$ to $150\text{ }^\circ\text{C}$, unless otherwise specified.

For definition of the parameters please see [Figure 29](#) and [Figure 30](#).

Table 34. SPI dynamic characteristics

| Symbol | Parameter | Test condition | Min | Typ | Max | Unit |
|---------------------|--|--|-----|-----|-----|---------------|
| t_{CSNQVL} | DO enable from tristate to low level | $C_{\text{DO}} = 100\text{ pF}$; $I_{\text{DO}} = 1\text{ mA}$; pull-up load to V_{CC} ; $V_{\text{CC1}} = 5.0\text{ V}$ | | 100 | 250 | ns |
| t_{CSNQVH} | DO enable from tristate to high level | $C_{\text{DO}} = 100\text{ pF}$; $I_{\text{DO}} = -1\text{ mA}$; pull-down load to GND; $V_{\text{CC1}} = 5.0\text{ V}$ | | 100 | 250 | ns |
| t_{CSNQTL} | DO disable from low level to tristate | $C_{\text{DO}} = 100\text{ pF}$; $I_{\text{DO}} = 4\text{ mA}$; pull-up load to V_{CC} ; $V_{\text{CC1}} = 5.0\text{ V}$ | | 380 | 450 | ns |
| t_{CSNQTH} | DO disable from high level to tristate | $C_{\text{DO}} = 100\text{ pF}$; $I_{\text{DO}} = -4\text{ mA}$; pull-down load to GND; $V_{\text{CC1}} = 5.0\text{ V}$ | | 380 | 450 | ns |
| t_{CLKQV} | CLK falling until DO valid | $V_{\text{DO}} < 0.3 V_{\text{CC}}$ or $V_{\text{DO}} > 0.7 V_{\text{CC}}$; $C_{\text{DO}} = 5\text{ pF}$; $V_{\text{CC1}} = 5.0\text{ V}$ | | | | ns |
| | | $V_{\text{DO}} < 0.3 V_{\text{CC}}$ or $V_{\text{DO}} > 0.7 V_{\text{CC}}$; $C_{\text{DO}} = 100\text{ pF}$; $V_{\text{CC1}} = 5.0\text{ V}$ | | | | ns |
| t_{SCSN} | CSN setup time, CSN low before rising edge of CLK | $V_{\text{CC1}} = 5.0\text{ V}$ | 400 | | | ns |
| t_{SDI} | DI setup time, DI stable before rising edge of CLK | $V_{\text{CC1}} = 5.0\text{ V}$ | 200 | | | ns |
| t_{HCLK} | minimum CLK high time | $V_{\text{CC1}} = 5.0\text{ V}$ | 115 | | | ns |
| t_{LCLK} | minimum CLK low time | $V_{\text{CC1}} = 5.0\text{ V}$ | 115 | | | ns |
| t_{HCSN} | minimum CSN high time | $V_{\text{CC1}} = 5.0\text{ V}$ | 4 | | | μs |
| t_{SCLK} | CLK setup time before CSN rising | $V_{\text{CC1}} = 5.0\text{ V}$ | 400 | | | ns |
| $t_{\text{r DO}}$ | DO rise time | $C_{\text{DO}} = 100\text{ pF}$; $V_{\text{CC1}} = 5.0\text{ V}$ | | 80 | 140 | ns |
| $t_{\text{f DO}}$ | DO fall time | $C_{\text{DO}} = 100\text{ pF}$; $V_{\text{CC1}} = 5.0\text{ V}$ | | 50 | 100 | ns |
| $t_{\text{r in}}$ | rise time of input signal DI, CLK, CSN | $V_{\text{CC1}} = 5.0\text{ V}$ | | | 100 | ns |
| $t_{\text{f in}}$ | fall time of input signal DI, CLK, CSN | $V_{\text{CC1}} = 5.0\text{ V}$ | | | 100 | ns |

Figure 29. SPI timing parameters

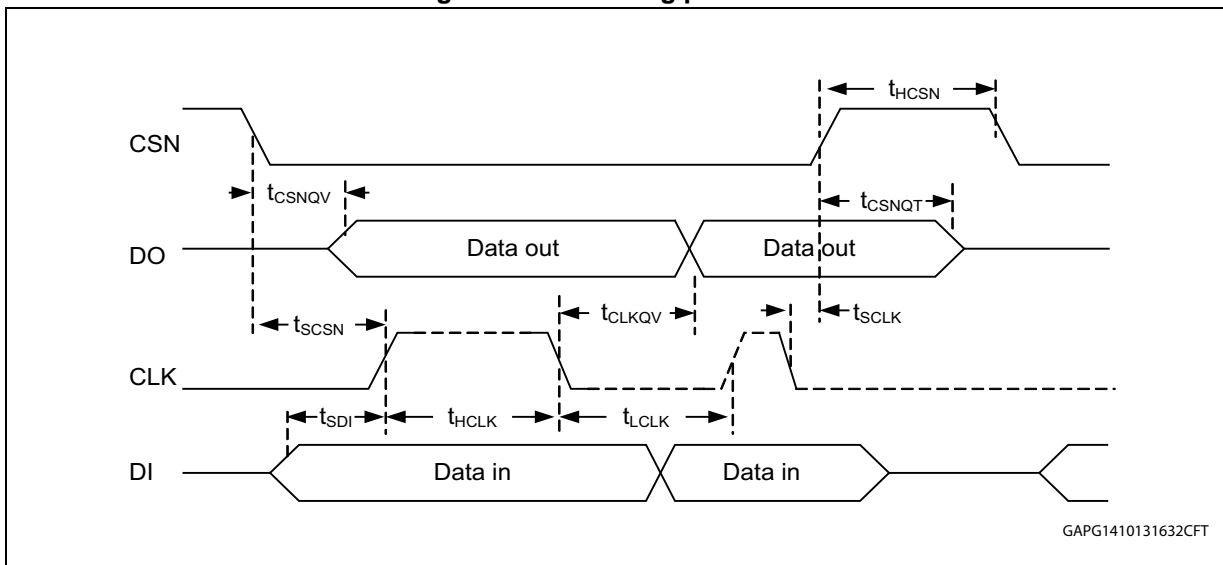


Figure 30. SPI input and output timing parameters

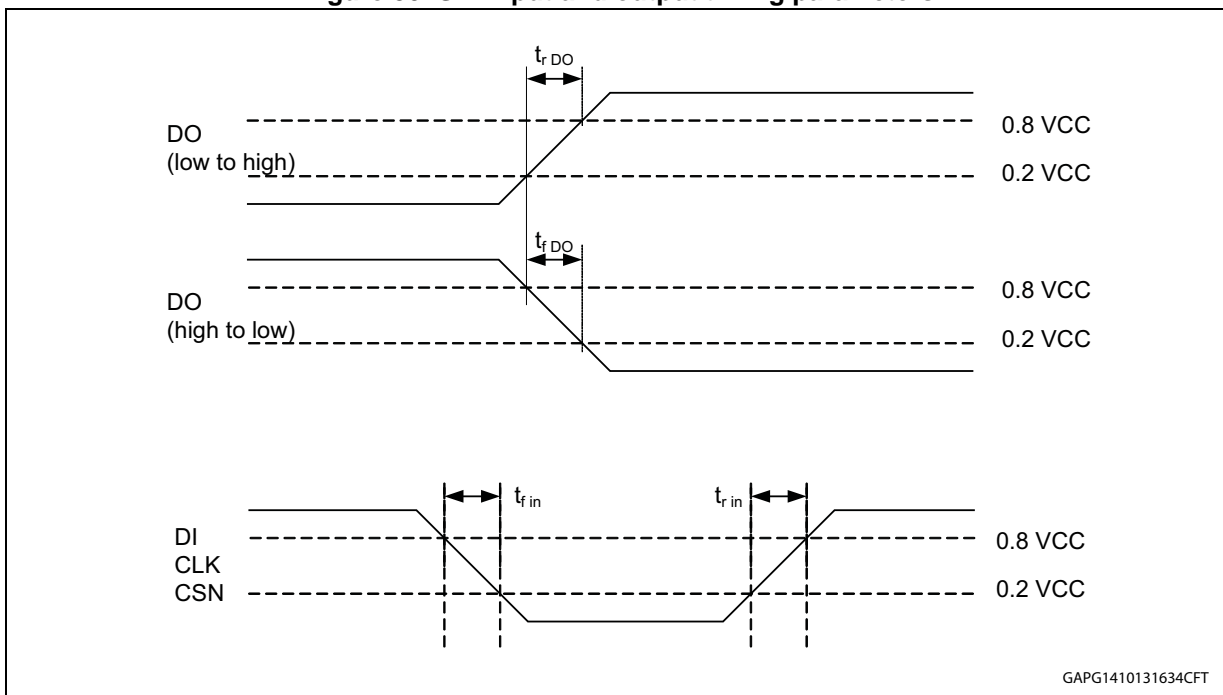
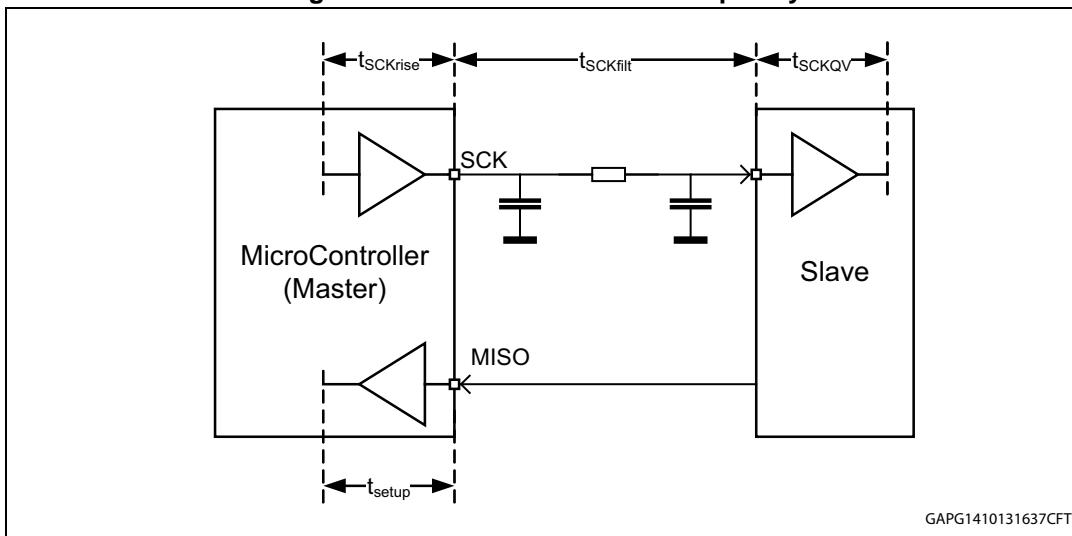


Figure 31. SPI maximum clock frequency



GAPG1410131637CFT

The maximum SPI clock frequency can be calculated as follows (see [Figure 31](#)):

$$t_{CLKQV}(total) = t_{CLKrise}(uC) + t_{CLKfilt}(PCB) + t_{CLKQV}(slave) + t_{setup}(uC)$$

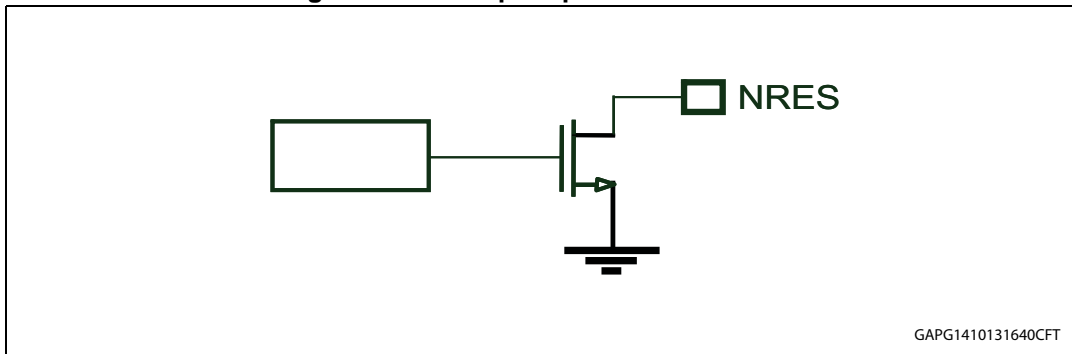
$$f_{CLK}(max) < \frac{1}{2} \times t_{CLKQV}(total)$$

Example:

$$t_{CLKQV} = 25 \text{ ns} + 100 \text{ ns} + 250 \text{ ns} + 25 \text{ ns} = 400 \text{ ns}$$

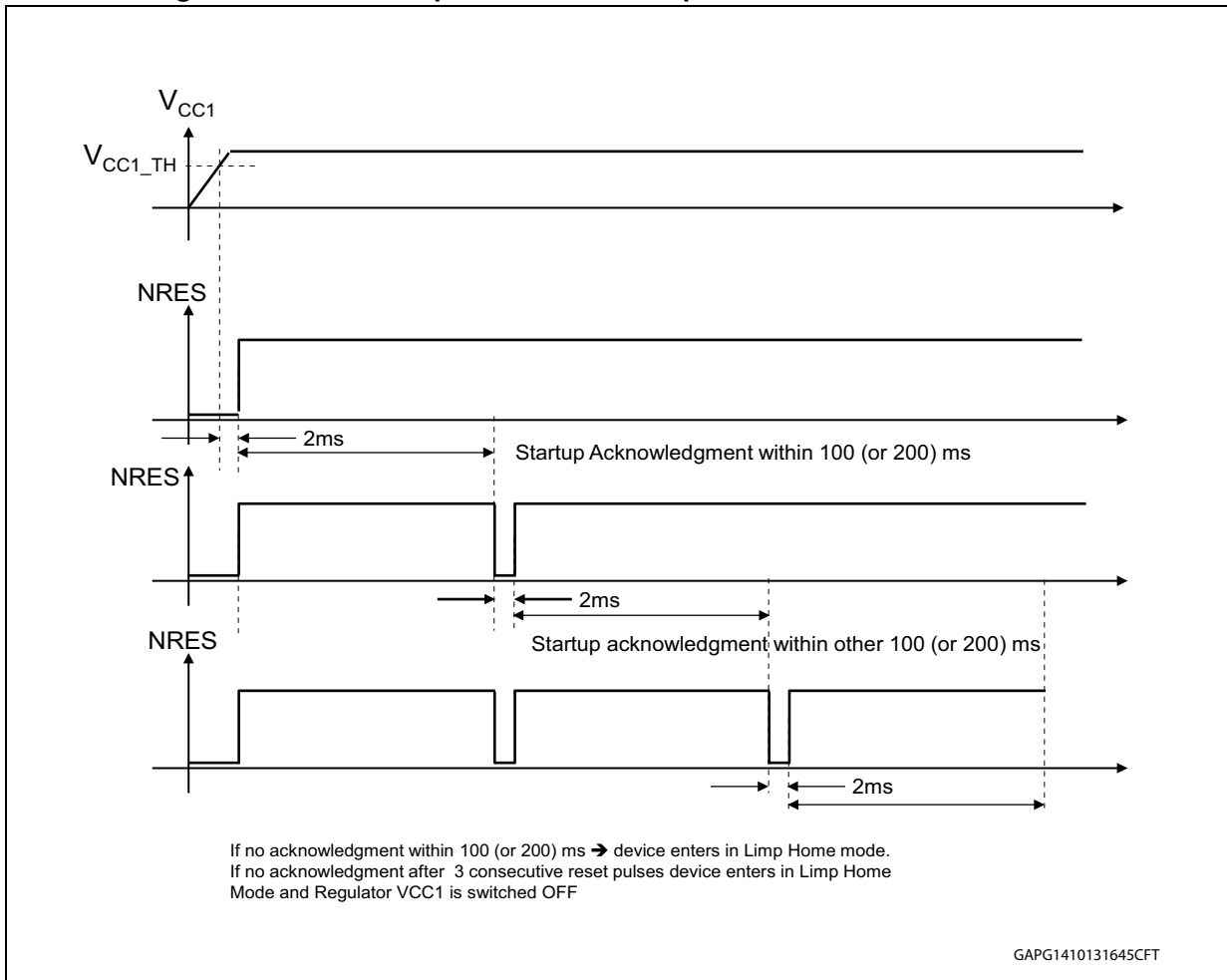
$$f_{CLK}(max) < 1.25 \text{ MHz}$$

Figure 32. NRES pin open drain structure



GAPG1410131640CFT

Figure 33. Handshake procedure at start up with microcontroller on board



7 Application circuits

Typical application circuits are shown on the following [Figure 34](#), [Figure 35](#) and [Figure 36](#). [Figure 37](#) shows the case of standalone application. [Figure 38](#) shows an example for the boost converter topology which uses an external Mosfet M3, for provide reverse battery protection, maintaining at same time a very low drop voltage in the normal functioning, but achieving low dissipation and high efficiency, in case of high power applications (LED headlamps).

Figure 34. Boost application circuit

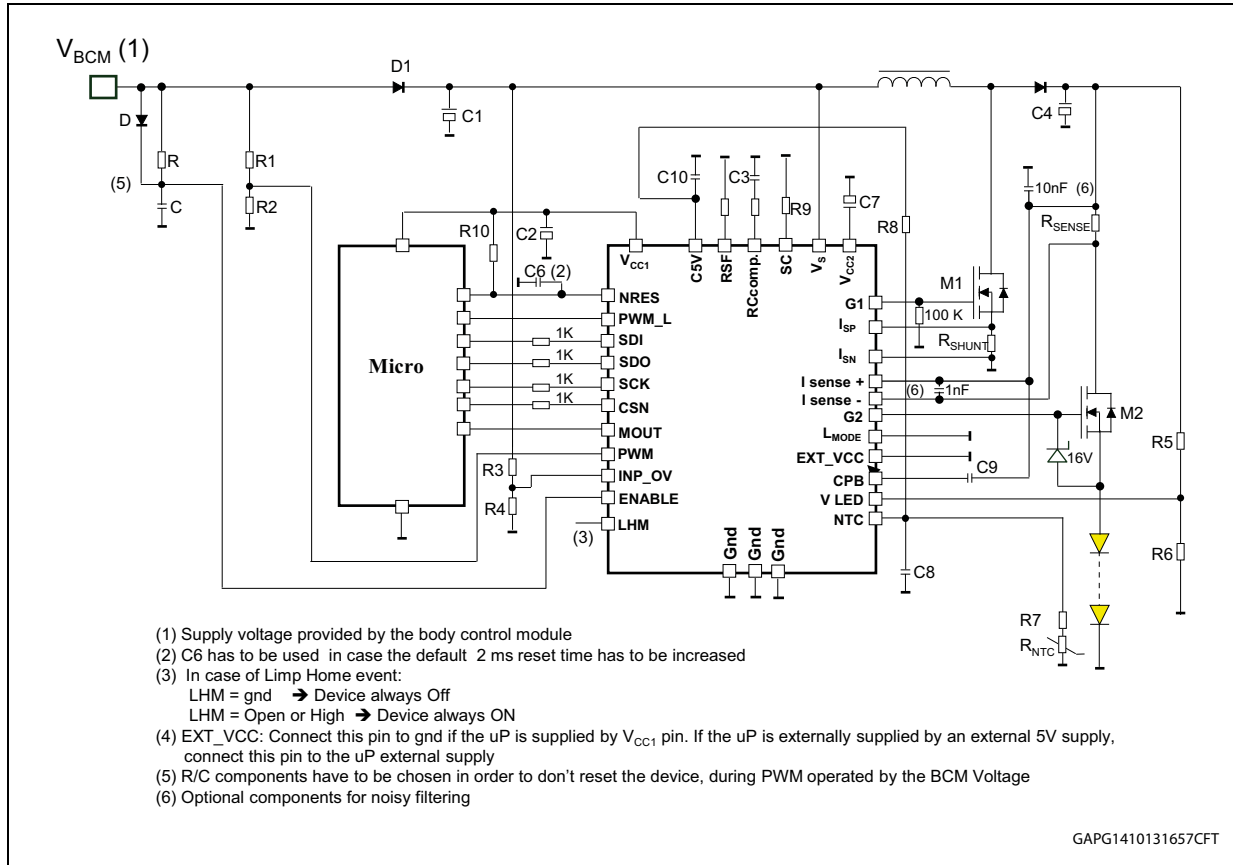


Figure 35. Fly back application circuit

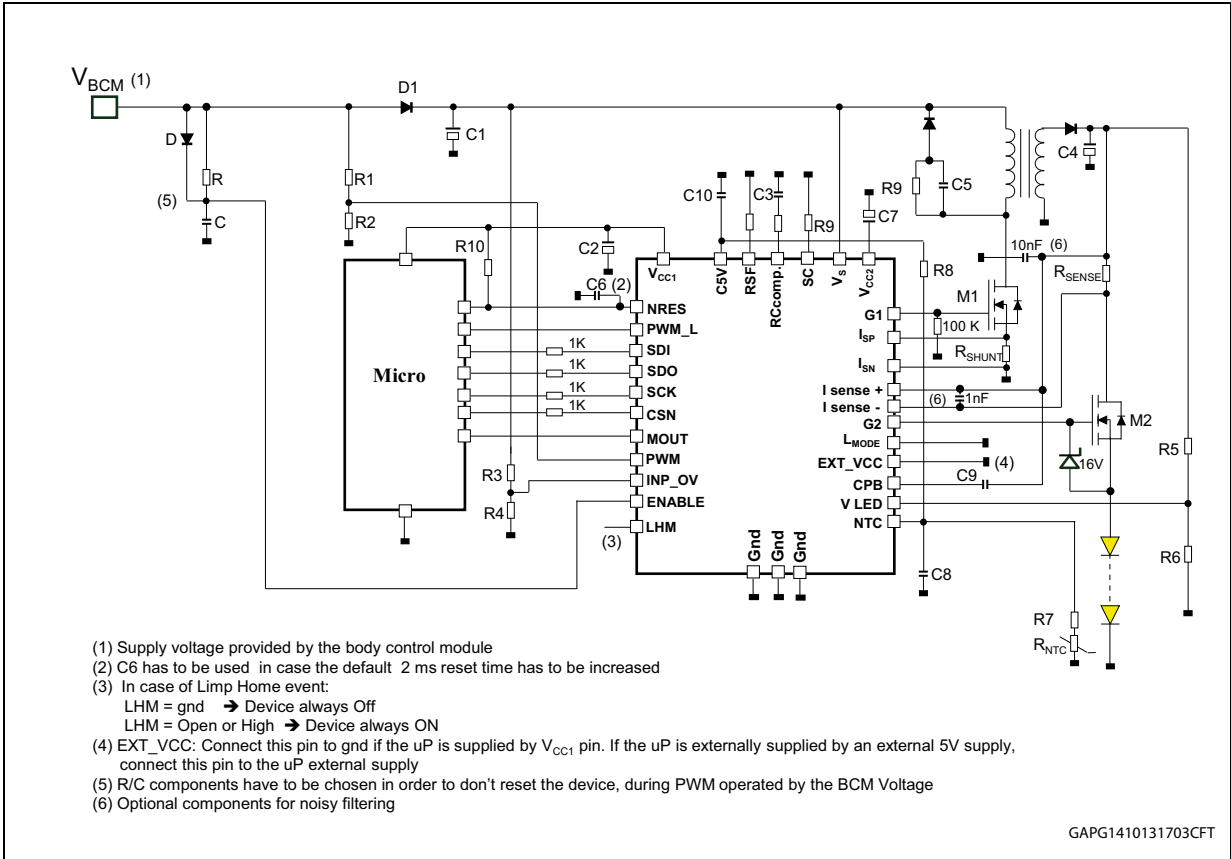


Figure 36. Buck-boost application circuit

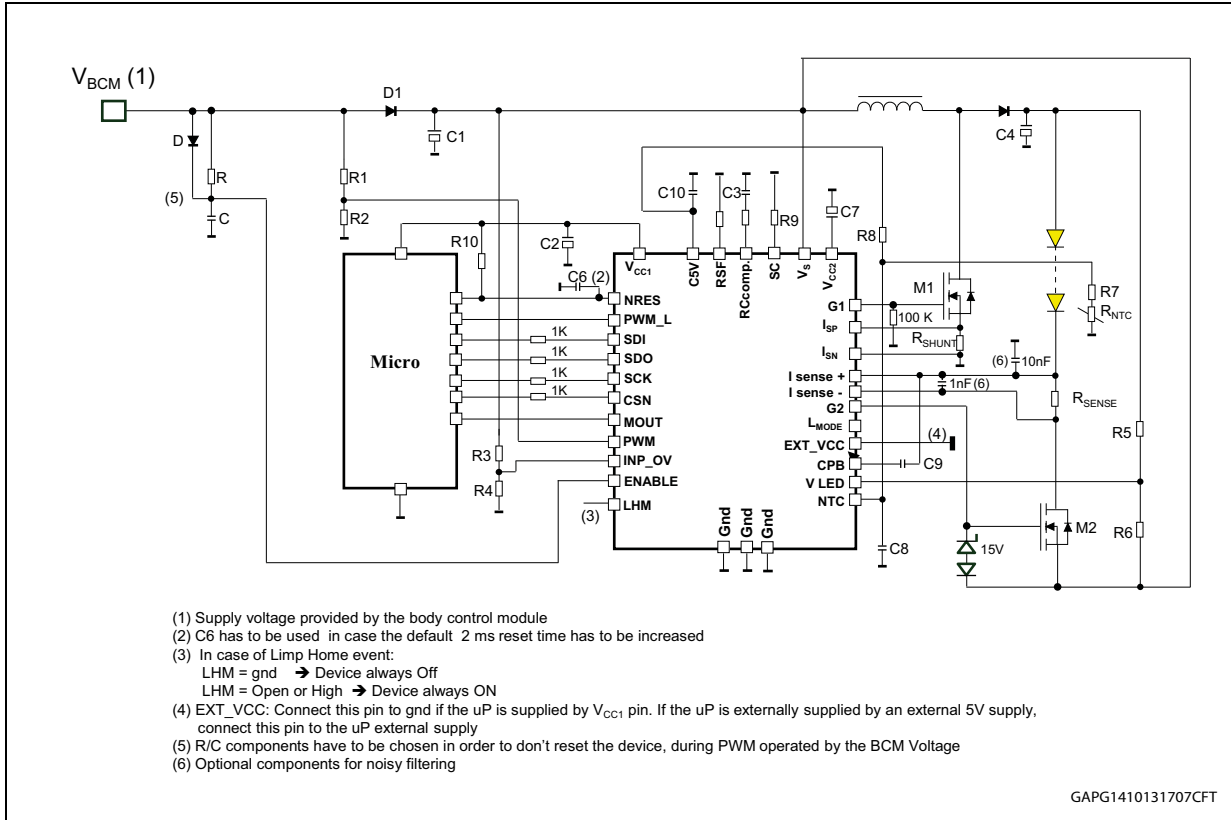


Figure 37. Stand alone application example for boost topology

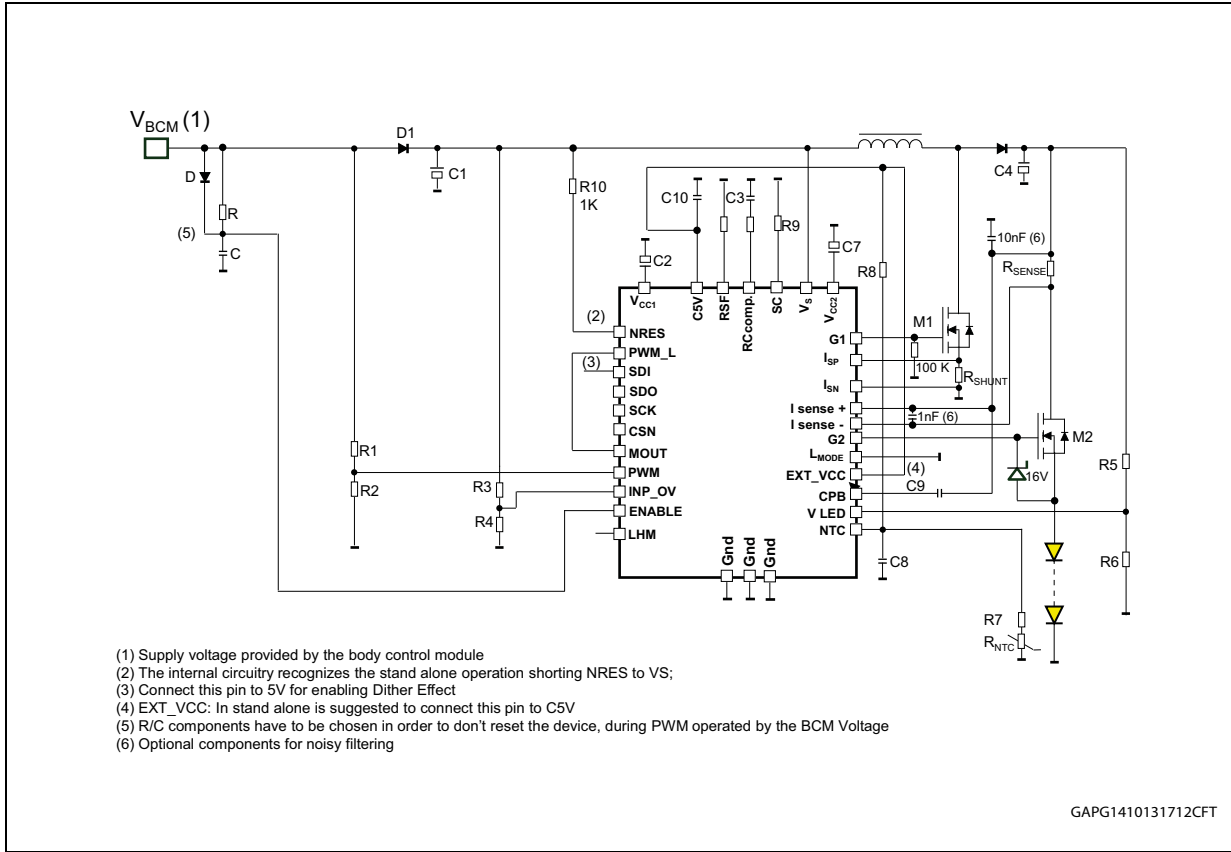
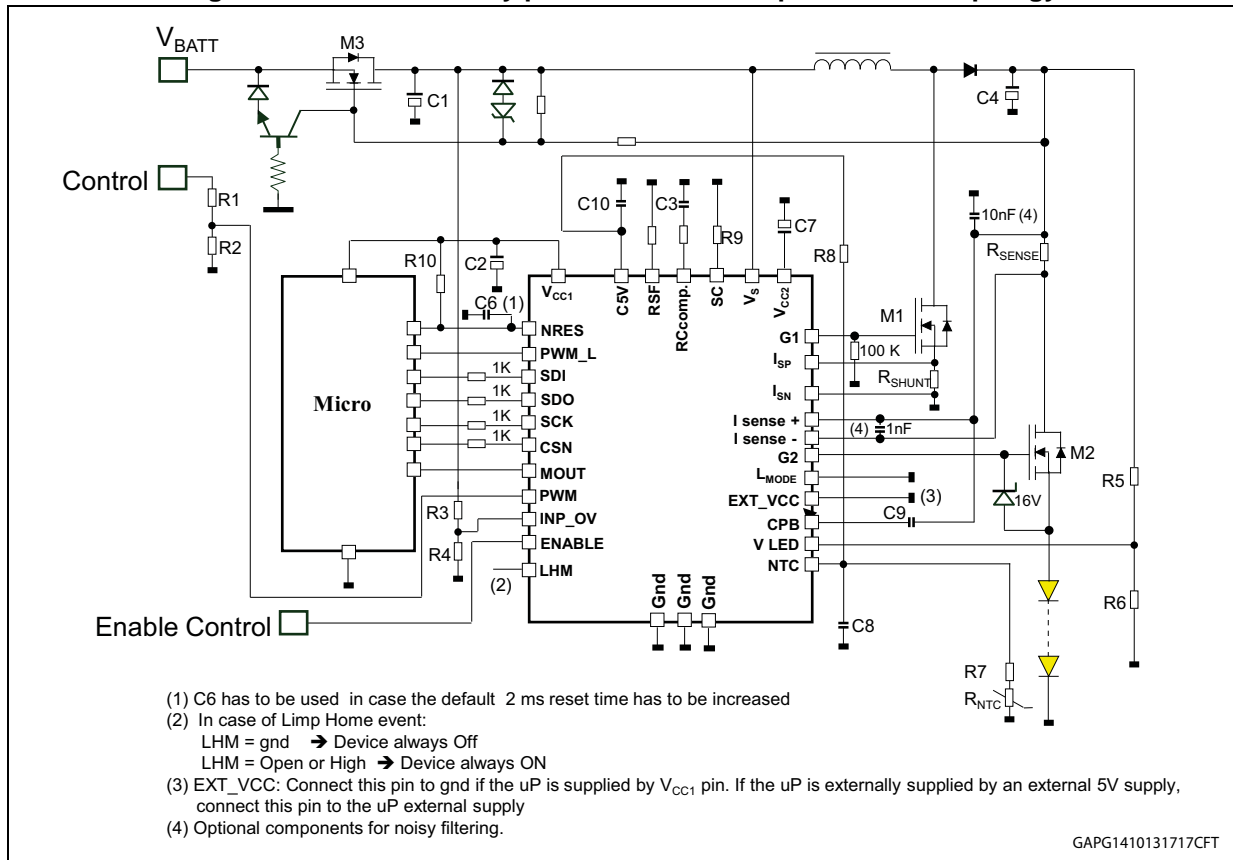
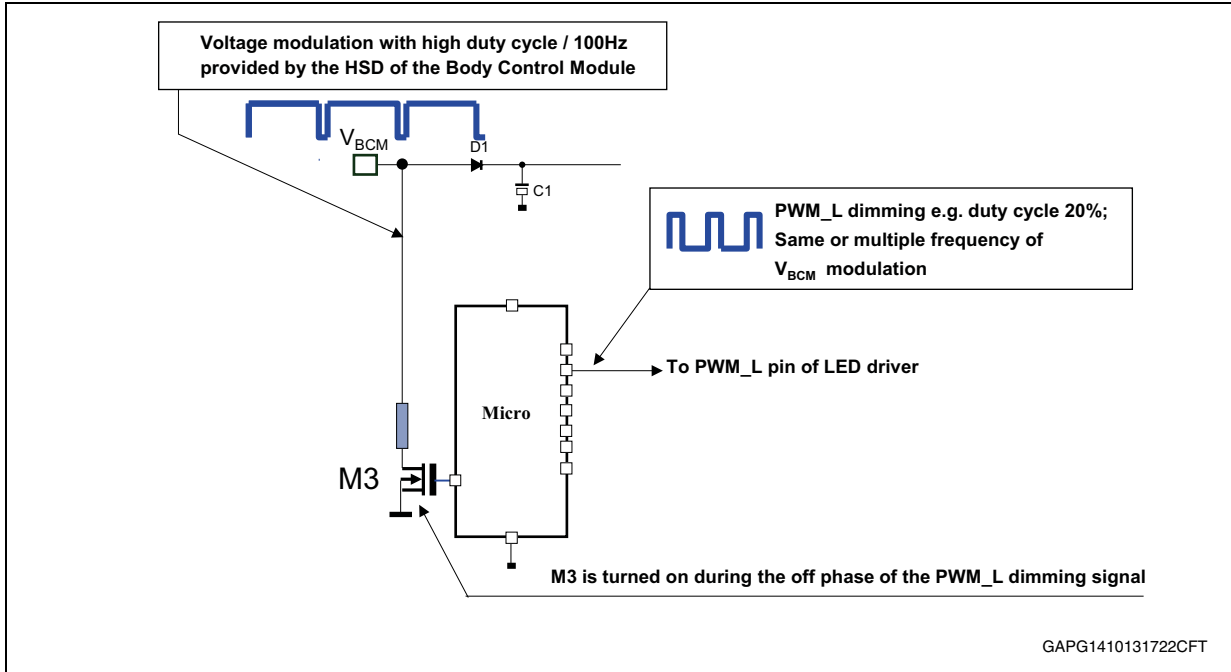


Figure 38. Reverse battery protection: an example for boost topology



If the DRL module is supplied by a high side driver (HSD) of the body control module (BCM), a minimum current consumption is requested during the off phase of the PWM dimming, so that the HSD of the BCM do not detect a wrong open load condition. This is in charge of the μ P which has to draw this “minimum current consumption”, from the supply line (see [Figure 39](#)).

Figure 39. External MOS required during PWM dimming



8 Package information

8.1 ECOPACK®

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.

8.2 LQFP32™ package information

Figure 40. LQFP32™ package dimensions

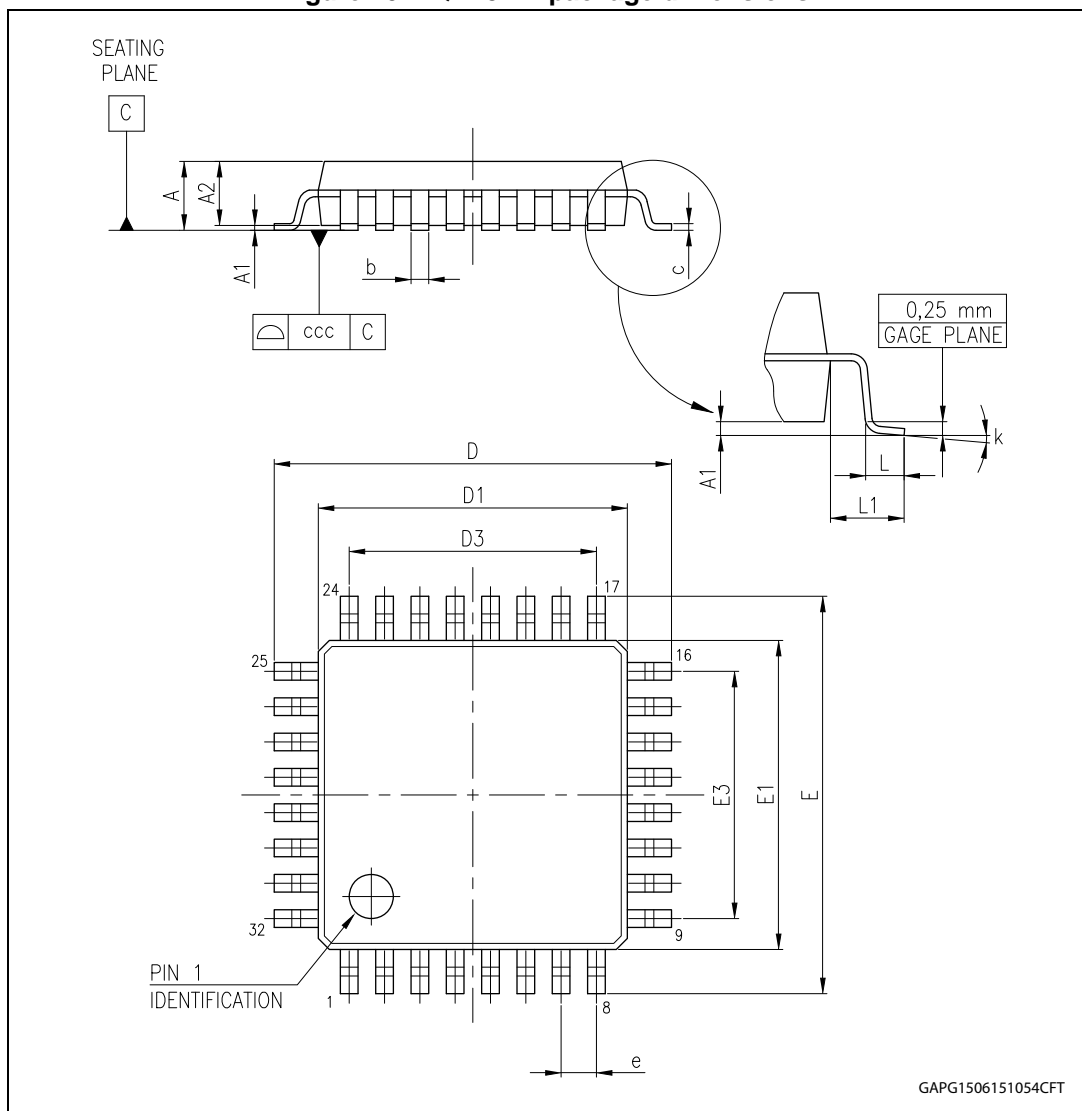


Table 35. LQFP32™ mechanical data

| Symbol | Millimeters | | |
|--------|-------------|------|------|
| | Min. | Typ. | Max. |
| A | | | 1.6 |
| A1 | 0.05 | | 0.15 |
| A2 | 1.35 | 1.40 | 1.45 |
| b | 0.30 | 0.37 | 0.45 |
| c | 0.09 | | 0.20 |
| D | 8.80 | 9.00 | 9.20 |
| D1 | 6.80 | 7.00 | 7.20 |
| D3 | | 5.60 | |
| E | 8.80 | 9.00 | 9.20 |
| E1 | 6.80 | 7.00 | 7.20 |
| E3 | | 5.60 | |
| L | 0.45 | 0.60 | 0.75 |
| L1 | | 1.00 | |
| K | 0° | 3.5° | 7° |
| ccc | | | 0.10 |

9 Order codes

Table 36. Device summary

| Package | Order code |
|---------|------------|
| | Tube |
| LQFP32 | L99LD01 |

10 Revision history

Table 37. Document revision history

| Date | Revision | Changes |
|-------------|----------|--|
| 19-Jun-2014 | 1 | Initial release. |
| 15-Jun-2015 | 2 | <p>Updated <i>Description</i></p> <p><i>Table 15: Absolute maximum ratings:</i></p> <ul style="list-style-type: none"> – V_{G1}, V_{G2}, V_{CPB}, $V_{ISENSE-}$: updated values <p><i>Table 16: Thermal data:</i></p> <ul style="list-style-type: none"> – $R_{Thj-case}$: updated values <p><i>Table 17: VS and V_{CC1} pin characteristics:</i></p> <ul style="list-style-type: none"> – t_{VSM}, t_{V1F}, t_{V1OT}: updated values – V_{CC1_DROP}: updated description – $t_{LMODERR}$, t_{OC}, t_{LEDOV}, t_{WD1}, t_{WD2}: added parameters <p><i>Table 19: NRES and LMODE pin characteristics:</i></p> <ul style="list-style-type: none"> – t_{RR}, t_{FS}, t_{RD}: updated values <p><i>Table 21: G2 pin characteristics (driver2):</i></p> <ul style="list-style-type: none"> – V_{G2_H}: updated values <p><i>Table 22: Converter oscillator and RSF pin characteristics:</i></p> <ul style="list-style-type: none"> – F_O: updated values – F_{O_S}: updated test conditions and values – Renamed “Duty cycle” symbol in “Duty cycle max”: updated test conditions and values – Renamed “T_{ON_MIN}” symbol in “Duty cycle min”: updated test conditions and values <p><i>Table 24: ISENSE+, ISENSE- pin, and O.T.A. characteristics:</i></p> <ul style="list-style-type: none"> – $V_{ISENSE+IR}$, $V_{ISENSE-IR}$: removed parameters – $V_{ISENSE+}$, $V_{ISENSE-}$, $(V_{ISENSE+} - V_{ISENSE-})_{TH}$, $V_{SENSE_MAX_1}$, V_{LREF_16}: updated values <p><i>Table 25: SC pin characteristics:</i></p> <ul style="list-style-type: none"> – V_{SC_low}, V_{SC_HIGH}: updated test conditions and values <p><i>Table 26: VLED pin characteristics:</i></p> <ul style="list-style-type: none"> – OV_TH1_VS, OV_TH2_VS: updated test conditions and values <p>Updated <i>Chapter 8: Package information</i></p> |
| 25-Jun-2015 | 3 | <p><i>Table 32: SPI DC characteristics:</i></p> <ul style="list-style-type: none"> – $I_{CLK\ in}$, $I_{DI\ in}$: updated maximum value |

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- Широкая линейка поставок активных и пассивных импортных электронных компонентов (более 30 млн. наименований);
- Поставка сложных, дефицитных, либо снятых с производства позиций;
- Оперативные сроки поставки под заказ (от 5 рабочих дней);
- Экспресс доставка в любую точку России;
- Помощь Конструкторского Отдела и консультации квалифицированных инженеров;
- Техническая поддержка проекта, помощь в подборе аналогов, поставка прототипов;
- Поставка электронных компонентов под контролем ВП;
- Система менеджмента качества сертифицирована по Международному стандарту ISO 9001;
- При необходимости вся продукция военного и аэрокосмического назначения проходит испытания и сертификацию в лаборатории (по согласованию с заказчиком);
- Поставка специализированных компонентов военного и аэрокосмического уровня качества (Xilinx, Altera, Analog Devices, Intersil, Interpoint, Microsemi, Actel, Aeroflex, Peregrine, VPT, Syfer, Eurofarad, Texas Instruments, MS Kennedy, Miteq, Cobham, E2V, MA-COM, Hittite, Mini-Circuits, General Dynamics и др.);

Компания «Океан Электроники» является официальным дистрибьютором и эксклюзивным представителем в России одного из крупнейших производителей разъемов военного и аэрокосмического назначения «JONHON», а так же официальным дистрибьютором и эксклюзивным представителем в России производителя высокотехнологичных и надежных решений для передачи СВЧ сигналов «FORSTAR».



JONHON

«JONHON» (основан в 1970 г.)

Разъемы специального, военного и аэрокосмического назначения:

(Применяются в военной, авиационной, аэрокосмической, морской, железнодорожной, горно- и нефтедобывающей отраслях промышленности)

«FORSTAR» (основан в 1998 г.)

ВЧ соединители, коаксиальные кабели, кабельные сборки и микроволновые компоненты:

(Применяются в телекоммуникациях гражданского и специального назначения, в средствах связи, РЛС, а так же военной, авиационной и аэрокосмической отраслях промышленности).



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