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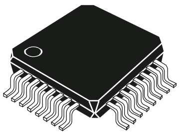
L99LD01

High efficiency constant current LED driver for automotive applications

Datasheet - production data



LQFP32
7x7 mm

GAPG1506151117CFT

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 (R9)
- Battery overvoltage shut down protection (ext. R3, R4 resistors required)
- Led chain OV detection (ext. R5, R6)
- 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 V ± 2 % -20 mA
- Parameter programming and settings of internal memory registers by the dedicated SPI interface:
  - LED current reference adjusting (± 66.7 %)
  - Maximum input current limiter reference adjusting (± 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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1 Block diagram and pin description

Figure 1. Block diagram

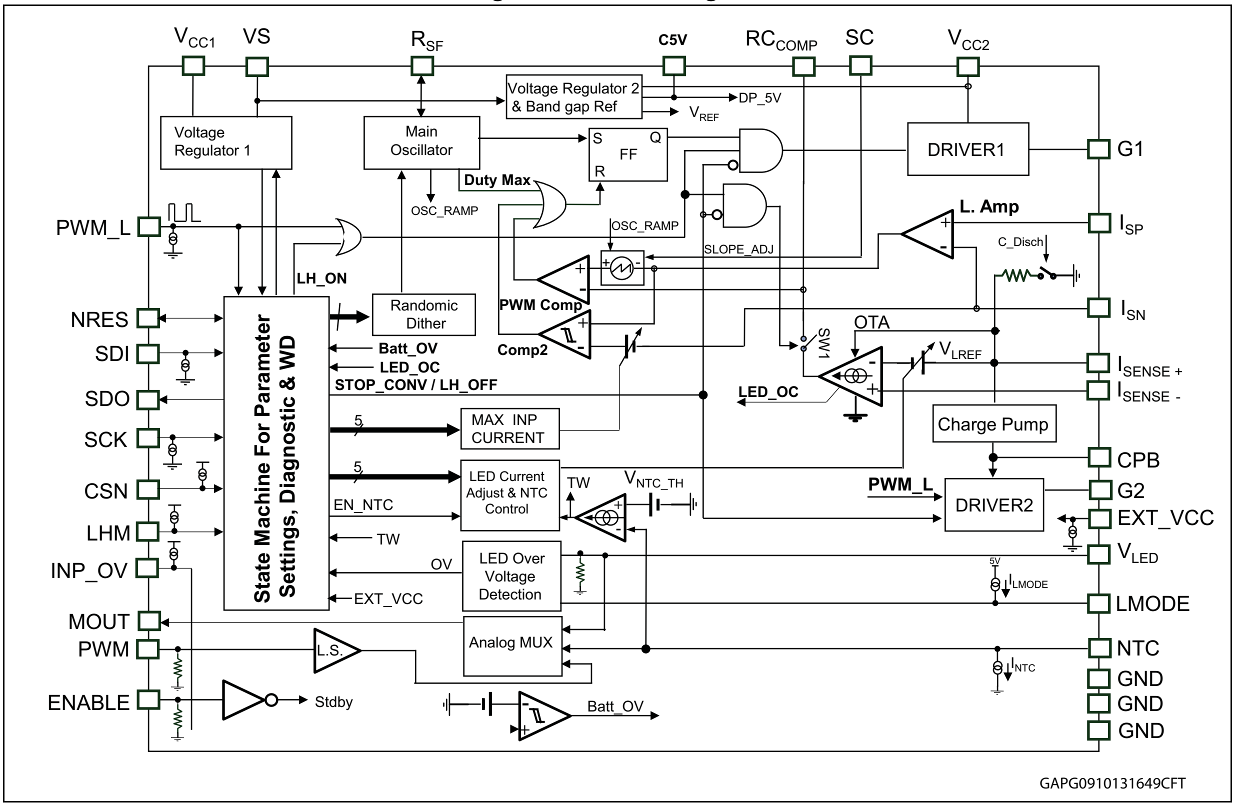


Figure 2. Connection diagram (top view – not in scale)

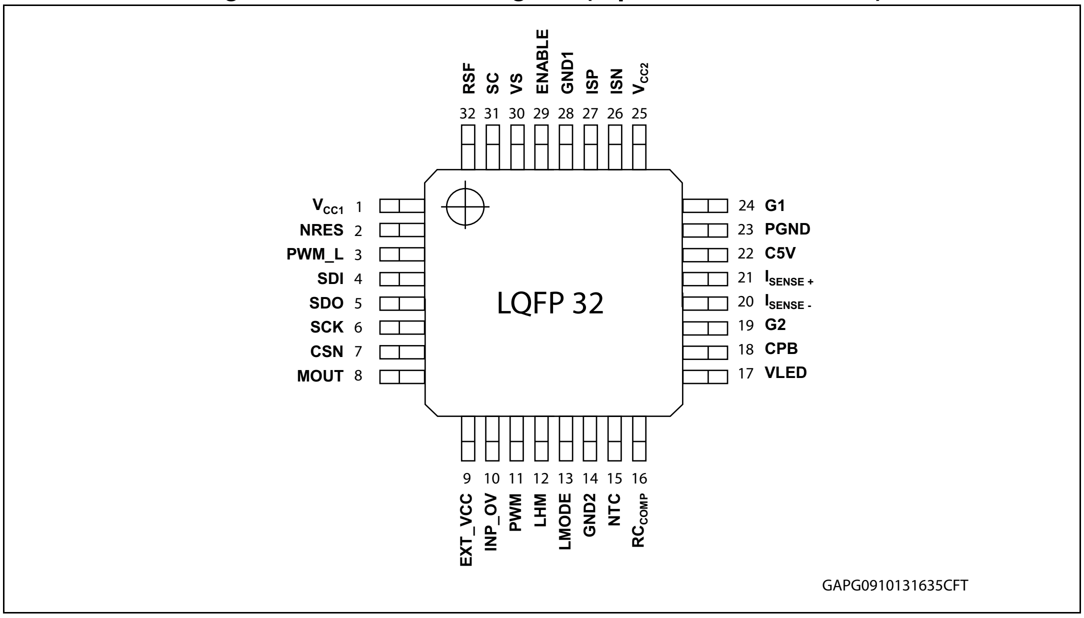


Table 1. Pin description

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:

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

- 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} = 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 Vcc1uv 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

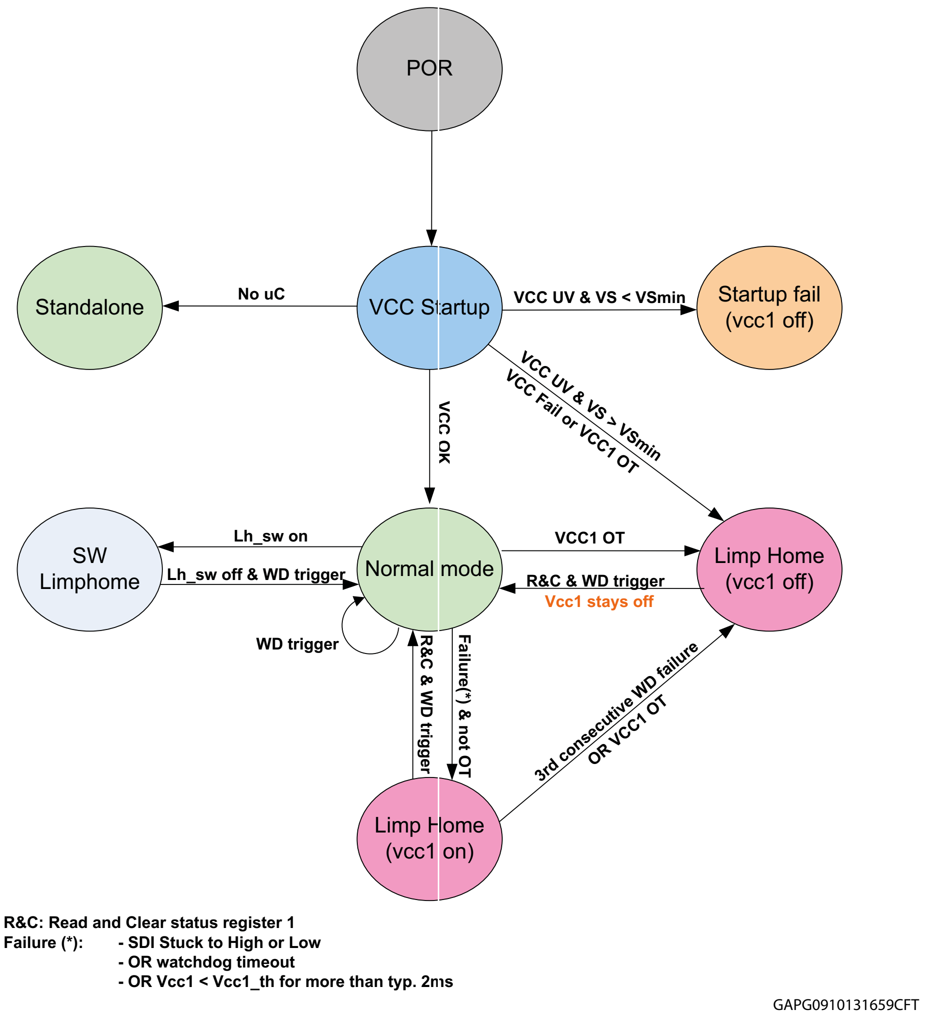


Table 2. Limp home mode: recovery paths

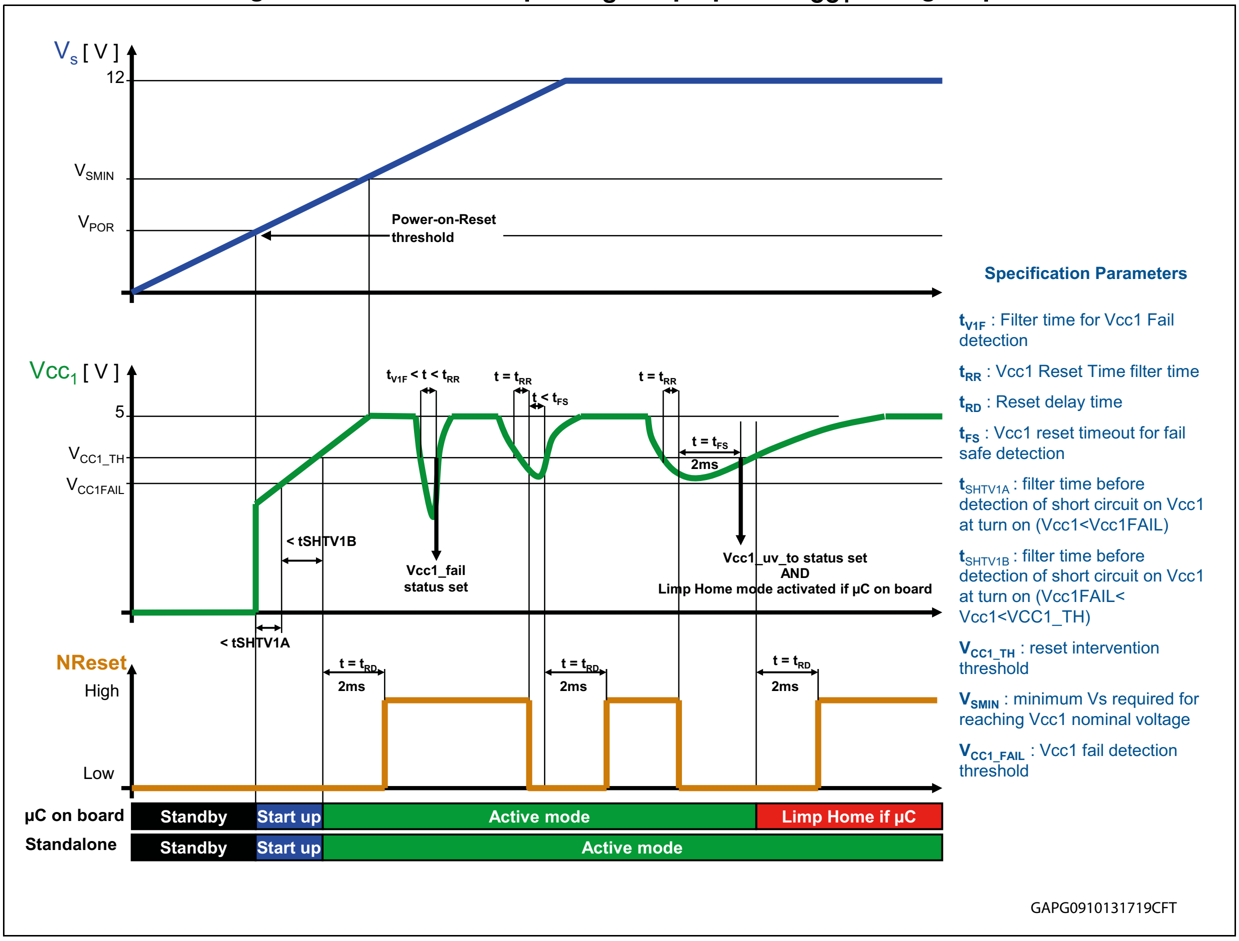
Transition	Root cause	Action to get back to normal mode	Response in the next SPI command
Normal mode → Limp Home V_{CC1} on	WD timeout (1st or 2nd WD timeout)	Read and clear status1 AND WD trigger	Fail Safe bit = 0 WD_Fail bit = 0
	$V_{CC1} < V_{CC1\_TH}$ for more than 2 ms		Fail Safe bit = 0 Vcc1_Uv_To 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

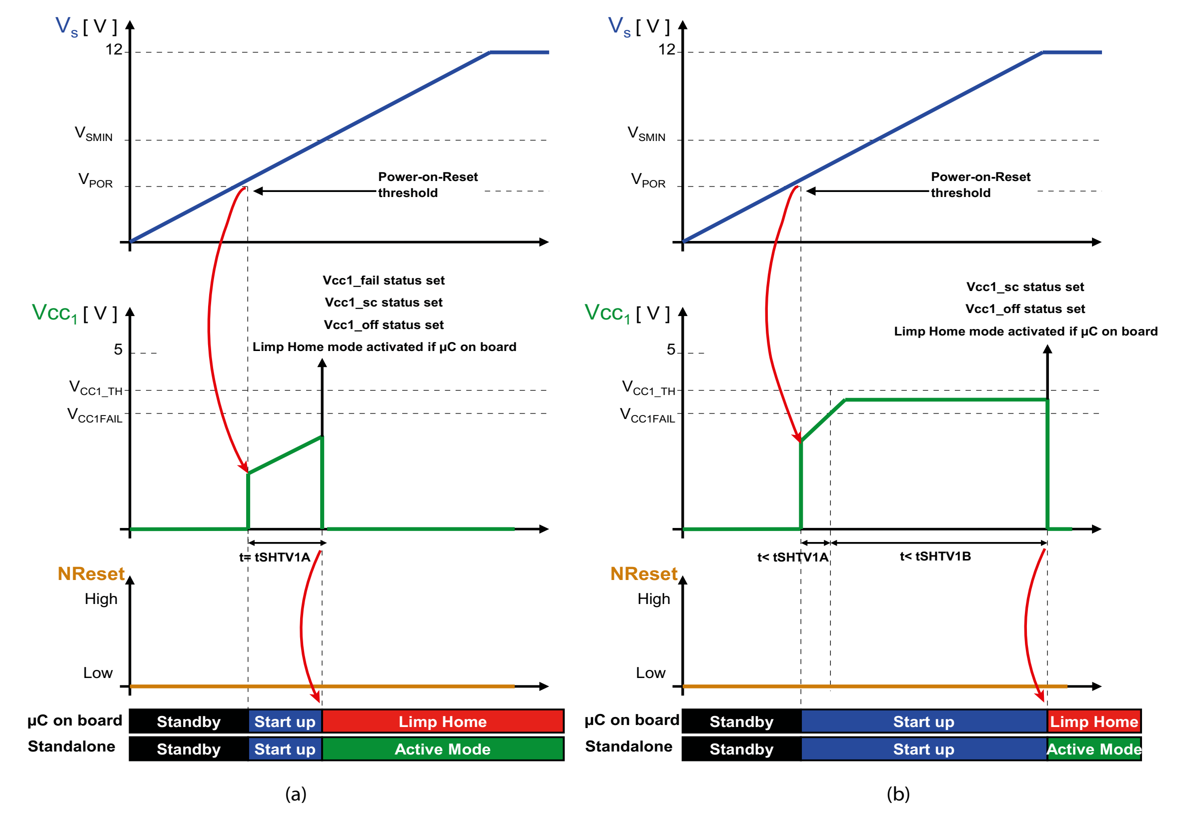
The following *Figure 4*, *Figure 5* (a), (b) and *Figure 6* (a) show the behavior of the device and NRES during start-up in case of normal V_S ramp up or in case of V_{CC1} failures (V_{CC1} fail or reset under voltage), both with microcontroller and standalone. *Figure 6* (b) and *Figure 7* show the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

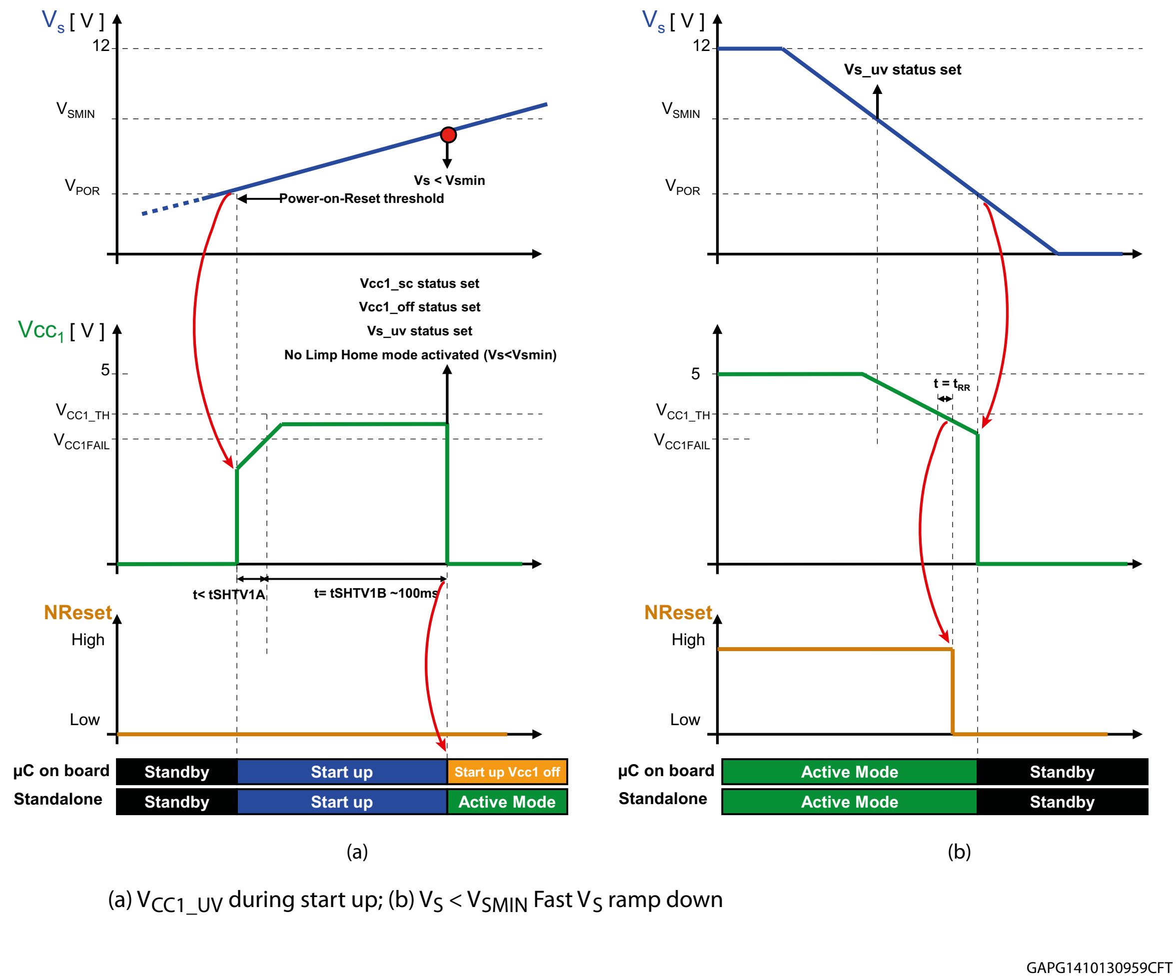
Figure 5. V_{CC1_FAIL} or V_{CC1} reset under voltage (V_S > V_{SMIN}) at start up



(a) start up V_{CC1} fail; (b) V_{CC1} under reset threshold during start up, $V_S > V_{SMIN}$

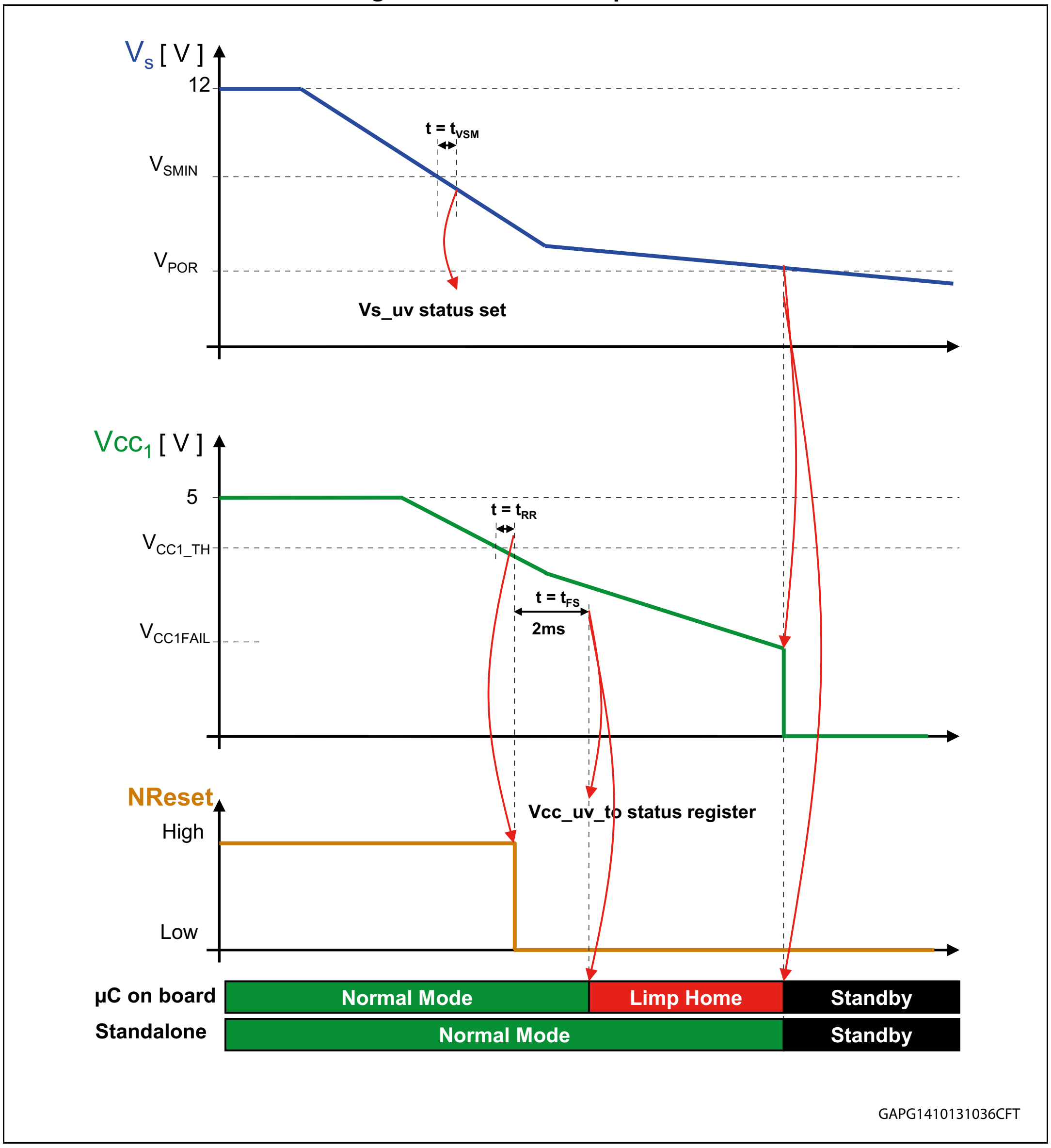
GAPG1410130949CFT

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

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 ± 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:

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

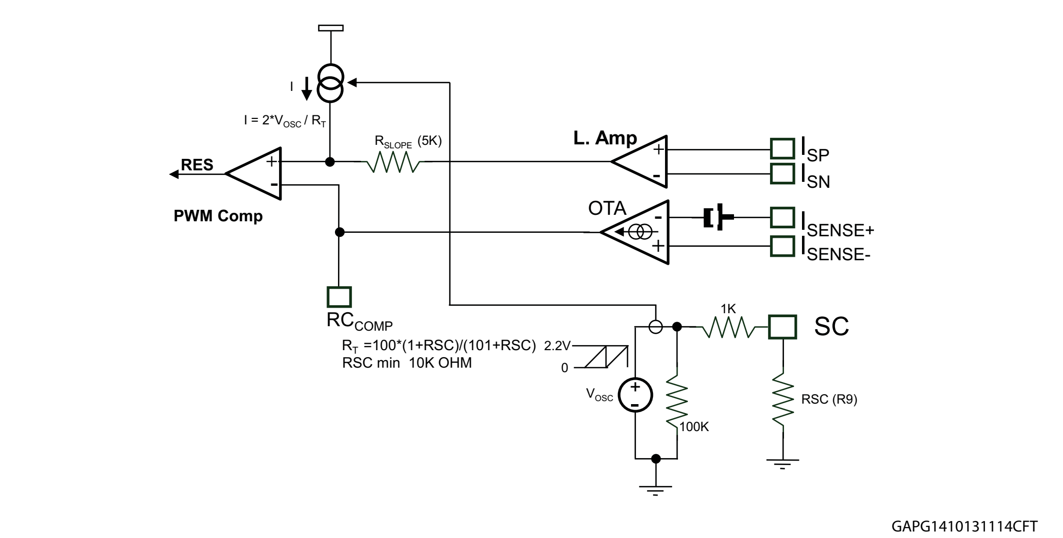
and consequently:

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

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 trough 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 trough 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

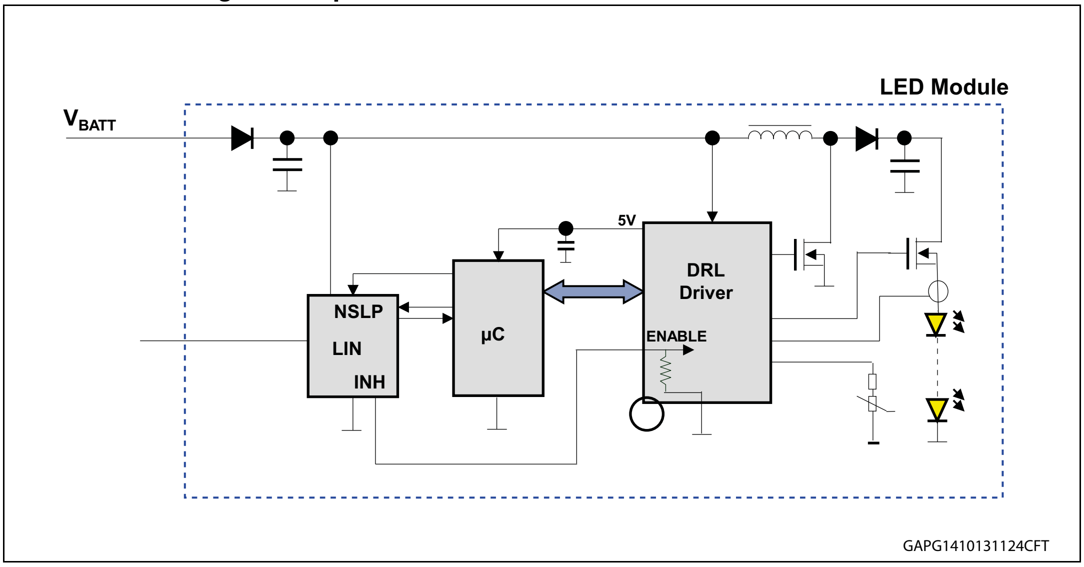
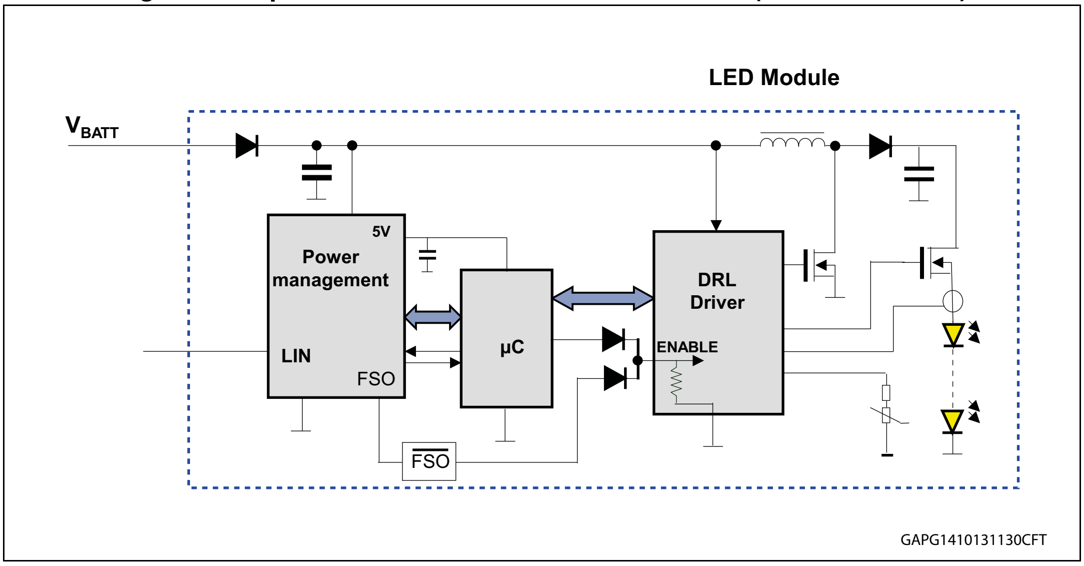


Figure 10. Operation with PM device and ENABLE (FSO active Low)



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

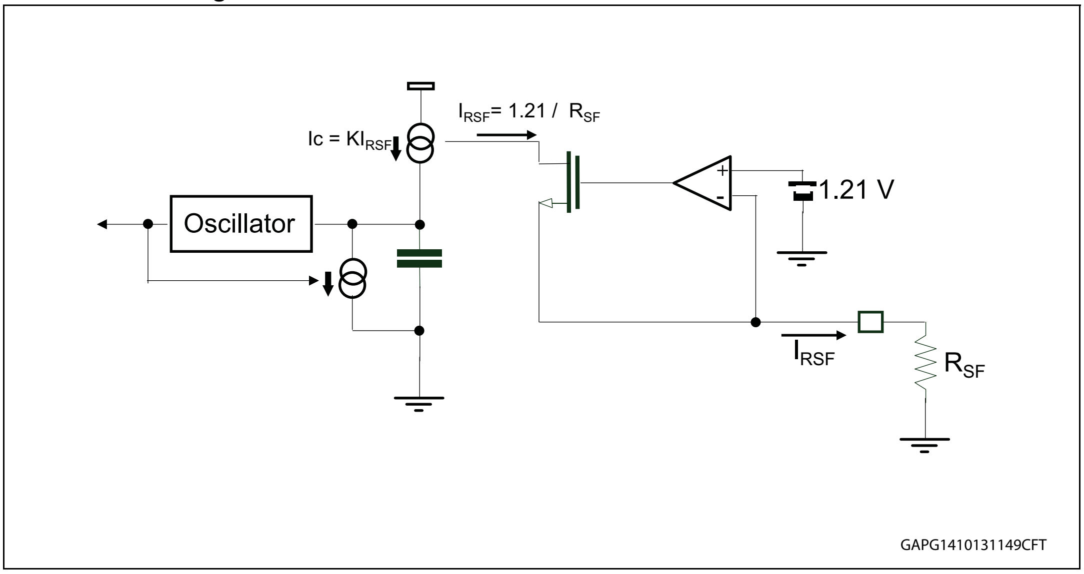
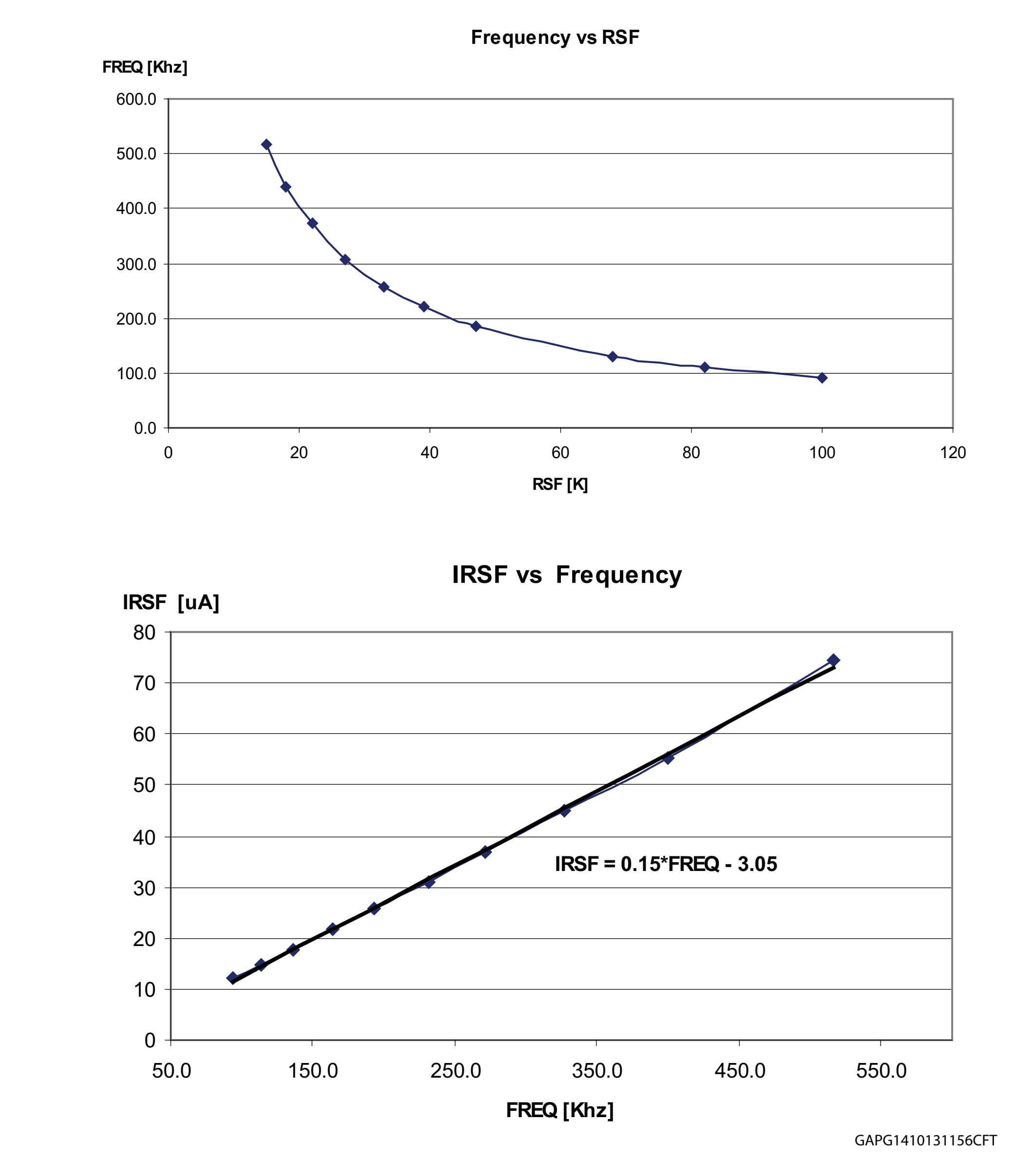


Figure 12. Converter frequency range vs R_{SF} and I_{RSF} vs frequency



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

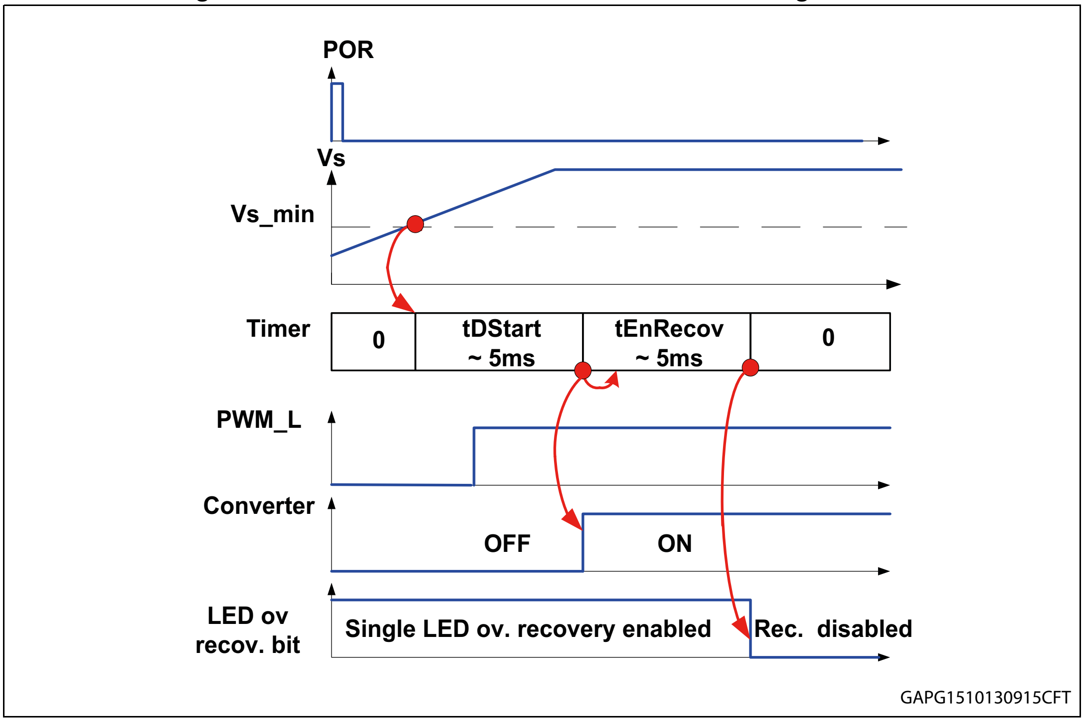


Figure 14. LED overvoltage after t_{DStart}