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1. Features

- AEC-Q100 qualified for automotive applications:
 - Device temperature grade 1:
 - 40°C to 125°C, T_A
- Input voltage operation range 3.5V to 36V
- Six high-precision current sinks
 - Up to 150mA DC current for each current sink
 - 2.5% Current Matching
- Internal 100mΩ, 50V MOSFET
- Configurable f_{sw} up to 2.2MHz
- External sync switching frequency function
- I2C/PWM dual dimming input scheme:
 - High resolution 16-bit LED dimming with I2C or PWM input
 - 15000:1 dimming ratio in PWM dimming mode when f_{PWM} ≤ 200Hz
- Multi-Dimming operation mode including:
 - Direct PWM dimming
 - Analog dimming with 200:1 dimming ratio
 - Mix dimming with 25% or 12.5% transfer point
- I2C Interface with 3 Selectable Device Addresses
- Excellent EMI performance, frequency spread spectrum
- Phase shift function for PWM dimming
- Comprehensive Protections
 - Cycle-by-cycle current limiting
 - Disconnect VOUT from VIN
 - Optional LED current automatically decrease at higher temperatures
 - LED short/open, OTP, OCP, and inductor short protection
 - Configurable LED short threshold
 - Configurable OVP threshold
 - Fault indicator signal output
- Available in QFN-24 (4mmx4mm) package

2. Applications

- Automotive infotainment
- Automotive instrument clusters
- Heads-up displays (HUD)

3. General Description

The LPQ3337 is an automotive high-efficiency boost LED driver with internal low on resistance NMOS. The device has six high precision current sinks which can support 150mA for each channel. It regulates the current in each LED string to the value set by an external current-setting resistor. LED brightness can be controlled globally through the I2C interface or PWM input.

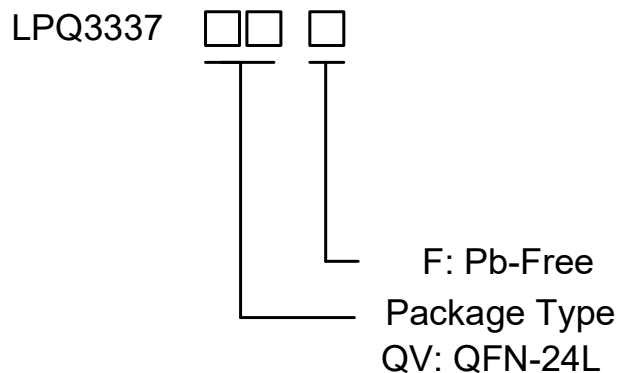
The LPQ3337 has a standard I2C digital interface for easy use. The switching frequency can be configured via an external resistor, the I2C interface, or an external clock signal.

The LPQ3337 provides analog dimming, PWM dimming, and mix dimming modes with a PWM input. The dimming mode can be selected via the I2C interface or the MODE pin. The device also has a phase shift function to eliminate noise during PWM dimming.

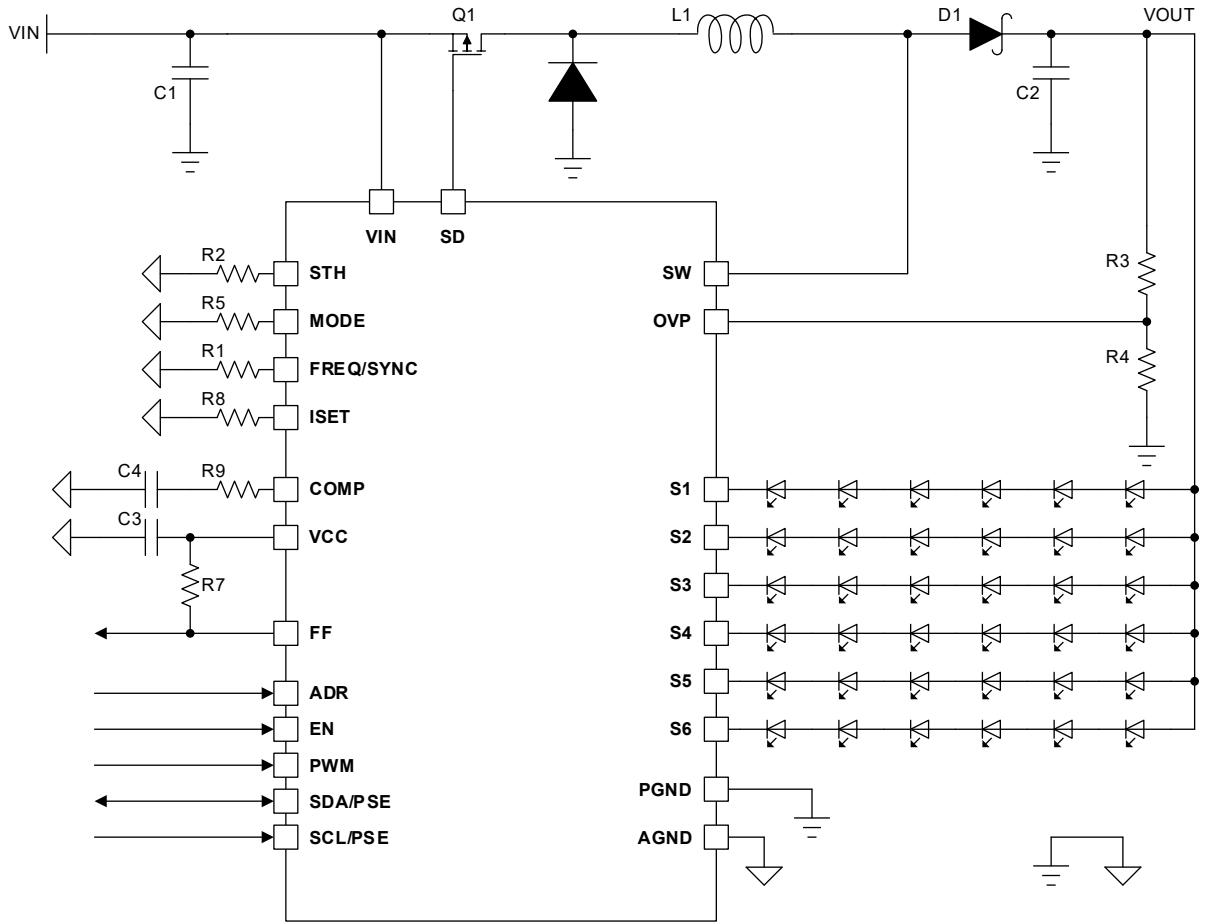
The LPQ3337 implements comprehensive protection modes including over-current protection (OCP), over-voltage protection (OVP), over-temperature protection (OTP), LED short protection, and LED open protection. The D970Q can automatically decrease the LED current when the junction temperature is higher than the threshold. This device is designed to drive the white LED arrays as backlighting for small-sized or medium-sized LCD panels.

The LPQ3337 is available in a QFN-24 (4mmx4mm) package, and the guaranteed operating ambient temperature range is -40°C to 125°C.

4. Order Information



5. Simplified Schematic

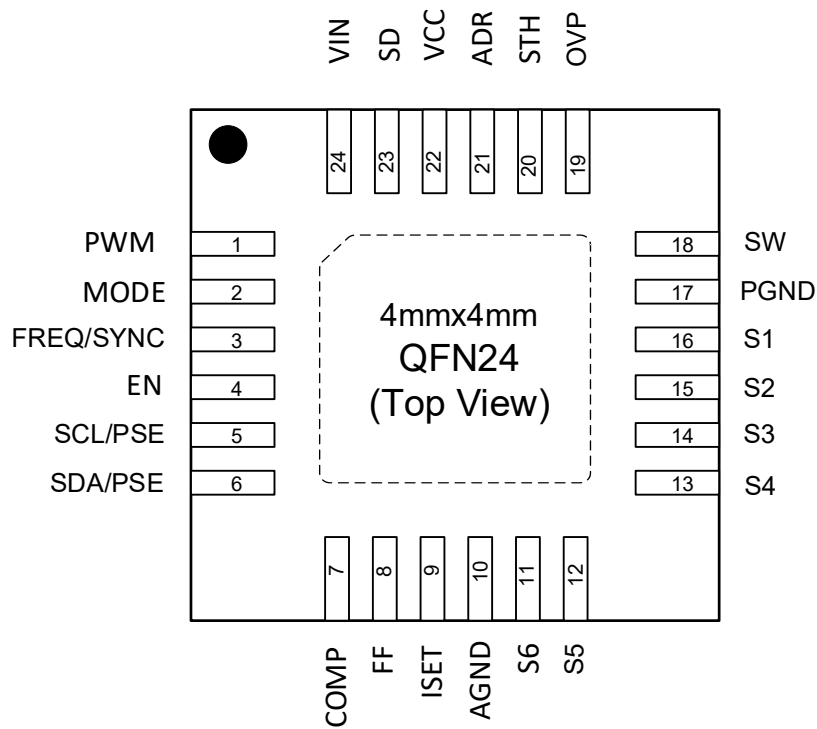


6. Device Information

Part Number	Top Marking	Moisture Sensitivity Level	Package	Shipping
LPQ3337QVF	LPS LPQ3337 YWX	MSL3	QFN-24(4mmx4mm)	3K/REEL

Marking indication:
Y: Year code. W: Week code. X: Batch numbers.

7. Pin Diagram



LPQ3337 QFN-24(4mmx4mm)

Note: Recommend connecting the Thermal Pad to the Ground for excellent power dissipation.

8. Pin Description

Pin#	Name	Description
1	PWM	PWM signal input pin. Apply a PWM signal on the PWM pin for brightness control. PWM is pulled low internally, and a 100Hz to 20kHz PWM signal is recommended.
2	MODE	Dimming mode setting pin. MODE is a current-source output (18 μ A). Connect a resistor from this pin to ground to configure its voltage. When MODE is low (<0.3V), the device uses the mix dimming mode. When MODE is at a middle level (0.5V to 0.8V), the device uses the PWM dimming mode. When MODE is high (1.0V to 1.3V), the device uses the analog dimming mode. When MODE is floating, the dimming mode is set by the internal MODE register. Please note, if the MODE pin uses the external resistor, the internal MODE register can't configure the dimming mode.
3	FREQ/SYNC	Switching frequency setting and SYNC pin. The switching frequency is determined by the voltage and current on this pin. Connect a resistor from this pin to ground to set the converter's switching frequency, or apply an external clock signal to this pin to synchronize the boost switching frequency. Leave this pin open if the internal switching frequency is set by FSW1:0.
4	EN	Device enable pin. Pull EN high to enable the device. Pull EN low to shut down the device.
5	SCL/PSE	I2C interface clock input pin. Connect SDA/PSE and SCL/PSE together and pull them up between 0.75V and 1V to enable the phase shift PWM dimming function. If the phase-shift function or I2C is not used, pull this pin to ground. Do not float this pin.
6	SDA/PSE	I2C interface data input pin. Connect SDA/PSE and SCL/PSE together and pull them up between 0.75V and 1V to enable the phase shift PWM dimming function. If the phase-shift function or I2C is not used, pull this pin to ground. Do not float this pin.
7	COMP	Compensation pin.
8	FF	Fault flag pin. Open drain during normal operation. FF is pulled low if a fault occurs.
9	ISET	LED current setting. Tie a current-setting resistor from ISET to GND to configure the current in each LED string.
10,	AGND	Analog ground.
11,	S6	LED string 6 current input. Connect the LED string 6 cathode to this pin.
12	S5	LED string 5 current input. Connect the LED string 5 cathode to this pin.
13	S4	LED string 4 current input. Connect the LED string 4 cathode to this pin.
14	S3	LED string 3 current input. Connect the LED string 3 cathode to this pin.
15	S2	LED string 2 current input. Connect the LED string 2 cathode to this pin.
16	S1	LED string 1 current input. Connect the LED string 1 cathode to this pin.
17	PGND	Step-up converter power ground.
18	SW	Drain for the internal low-side MOSFET switch. Connect the power inductor to SW.
19	OVP	Over-voltage protection pin. Connect a resistor divider from the OVP pin to GND to configure the over-voltage protection threshold.
20	STH	Short LED protection threshold setting pin. STH is a current-source output (18 μ A). Connect a resistor from this pin to ground to configure its voltage. Leave this pin open if the internal short LED protection threshold is set by TH_S1:0.
21	ADR	Device address setting pin. STH is a current-source output (18 μ A). Connect a resistor from this pin to ground to set the device address. When ADR is floating, the device address is 0x38. When ADR < 0.4V, the device address is 0x3A. When ADR is between 0.4V and 1.4V, the device address is 0x39.
22	VCC	5V LDO output pin. VCC provides power to the internal logic and gate driver. Place a ceramic capacitor as close to this pin as possible to reduce noise.
23	SD	External disconnect P-channel MOSFET (PMOS) gate drive pin. Turn off the external PMOS if a fault occurs. Float this pin if it is not used.
24	VIN	Power supply input. VIN supplies power to the device.
	EP	Exposed pad, connect the exposed pad to chip ground.

9. Absolute Maximum Ratings (Note1)

VIN	-----	-0.3V to 42V
SW, S1 to S6	-----	-0.5V to +50V
SW	-----	-1.0V for <100ns
SD	-----	VIN-6V to VIN
All other pins	-----	-0.3V to +6V

Note1: Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

10. ESD Ratings (Note2)

HBM (Human Body Model) S1~S6 ESD	-----	7KV
All other pins	-----	4KV
CDM (Charge Discharge Model)	-----	2KV

Note2: Devices are ESD sensitive. Handling precaution is recommended.

11. Thermal Information

Junction Temperature (TJ)	-----	150°C
Operating Junction Temperature Range (TJ)	-----	-40°C to 150°C
Ambient Temperature Range	-----	-40°C to 125°C
Storage Temperature Range	-----	-65°C to 150°C
Maximum Soldering Temperature (at leads, 10 sec)	-----	260°C
θ_{JA} (Junction-to-Ambient Thermal Resistance)	-----	TBD°C/W
θ_{JC} (Junction-to-Case Thermal Resistance)	-----	TBD°C/W

12. Electrical Characteristics

Limits apply over the full operation temperature range -40°C to +125°C, unless otherwise specified.

$V_{IN} = 12V$, $V_{EN} = 2V$

SYMBOL	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
GENERAL						
V_{IN}	Operating input voltage		3.5		36	V
I_Q	Quiescent supply current	No switching		5		mA
I_{ST}	Shutdown supply current	$V_{IN} = 12V$, $V_{EN} = 0V$			1	μA
V_{IN_UVLO}	Input UVLO threshold	V_{IN} rising		3.1		V
	Input UVLO hysteresis			100		mV
V_{CC}	LDO output voltage	$6V < V_{IN} < 24V$, $V_{EN} = 2V$, $0 < I_{VCC} < 10mA$		5		V
V_{EN_ON}	EN on threshold	V_{EN} rising	1.2			V
V_{EN_OFF}	EN off threshold	V_{EN} falling			0.4	V
R_{EN}	EN pull-down resistance			1		M Ω
Step-Up Converter						
R_{ON_LS}	Low-side MOSFET on resistance	$V_{IN} = 12V$		100		m Ω
I_{SW_LK}	SW leakage current	$V_{SW} = 45V$			1	μA
f_{SW}	Switching frequency	$R_{FREQ} = 10k\Omega$	1.98	2.2	2.42	MHz
		$R_{FREQ} = 40k\Omega$	495	550	605	kHz
		$FSW1:0 = 01$, FREQ floating	340	400	460	kHz
$V_{FREQ/SYNC}$	FREQ/SYNC voltage		0.57	0.6	0.63	V
I_{ADR}	ADR pull-up current			18		μA
D_{MAX}	Maximum duty cycle	$f_{SW} = 1MHz$	90			%
I_{SW_LIMIT}	Cycle-by-cycle current limiting	$T_J = +25^\circ C$, duty = 90%	2.6			A
		duty = 90%	2.3			A
I_{CL}	Current limit protection	To trigger current limit protection		6		A
V_{SYNC_LO}	SYNC input low threshold	V_{SYNC} falling			0.4	V
V_{SYNC_HI}	SYNC input high threshold	V_{SYNC} rising	1.2			V
V_{PSE}	PSE active threshold	Phase shift enabled	0.75	0.9	1.0	V
G_{COMP}	COMP trans-conductance	$\Delta I_{COMP} \leq 10\mu A$		100		$\mu A/V$
I_{COMP_SO}	COMP source current limit			90		μA
I_{COMP_SI}	COMP sink current limit			30		μA
Current Dimming						
V_{PWM_IL}	PWM input low threshold	V_{PWM} falling			0.4	V
V_{PWM_IH}	PWM input high threshold	V_{PWM} rising	1.2			V
PWM_PD	PWM pull-down resistance			500		k Ω
V_{MODE_IL}	MODE input low threshold	Mix dimming threshold			0.3	V
V_{MODE_IM}	MODE input middle threshold	PWM dimming threshold	0.5		0.8	V
V_{MODE_IH}	MODE input high threshold	Analog dimming threshold	1.0		1.3	V
I_{MODE}	MODE pull-up current			18		μA
MIX_{TRANS}	Mix dimming transfer point	MIXTP bit = 0		25		%
	Transfer point hysteresis			0.5		%

SYMBOL	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
f _{MIX}	Mix dimming output dimming frequency	MIXFR bit = 0		200		Hz

Electrical Characteristics (continued)

Limits apply over the full operation temperature range -40°C to +125°C, unless otherwise specified.

V_{IN} = 12V, V_{EN} = 2V

SYMBOL	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
LED Current Regulator						
V _{HD}	LED S1 to S6 regulation voltage	I _{LED} = 20mA		350		mV
		I _{LED} = 100mA		850	1000	mV
I _{MATCH}	Current matching ⁽¹⁾	I _{LED} = 20mA	-2.5		+2.5	%
		I _{LED} = 100mA	-2.5		+2.5	%
V _{ISET}	ISET voltage			1.2		V
I _{LED}	LED current	R _{ISET} = 24.9kΩ, T _J = 25°C	48.75	50	51.25	mA
		I _{LED} = 1 / 50 x 50mA = 1mA	0.9	1.05	1.2	mA
PH _{SHIFT}	Phase shift degree	LED1 to LED6 enabled		60		°
		LED1 to LED4 enabled		90		°
Protection						
V _{OVP}	Over-voltage protection threshold		1.9	2	2.1	V
	OVP hysteresis			200		mV
V _{OVP_UV}	OVP UVLO threshold	Step-up converter fails		100		mV
V _{LED_OV}	LED S1 to S6 over-voltage threshold	TH_S bits = 01		5		V
	LED S1 to S6 OV fault timer			7.7		ms
V _{LED_UV}	LED S1 to S6 UVLO threshold			100		mV
T _{SD}	Thermal shutdown threshold ⁽²⁾	Rising edge		170		°C
		Hysteresis		20		°C
I _{SD}	SD pull-down current			60		μA
V _{SD_IN}	SD voltage (relative to V _{IN})	V _{IN} = 12V, V _{IN} - V _{SD}		6		V
I _{STH}	STH pull-up current			18		μA
I2C Interface						
V _{IL}	Input logic low				0.4	V
V _{IH}	Input logic high		1.2			V
V _{OL}	Output logic low	I _{LOAD} = 3mA			0.4	V
f _{SCL}	SCL clock frequency ⁽²⁾				400	kHz
t _{HIGH_SCL}	SCL high time ⁽²⁾		0.6			μs
t _{LOW_SCL}	SCL low time ⁽²⁾		1.3			μs
t _{SU_DAT}	Data set-up time ⁽²⁾		100			ns
t _{HD_DAT}	Data hold time ⁽²⁾		0		0.9	μs
t _{SU_STA}	Set-up time for a repeated START ⁽²⁾		0.6			μs

Electrical Characteristics (continued)

Limits apply over the full operation temperature range -40°C to +125°C, unless otherwise specified.
 $V_{IN} = 12V$, $V_{EN} = 2V$

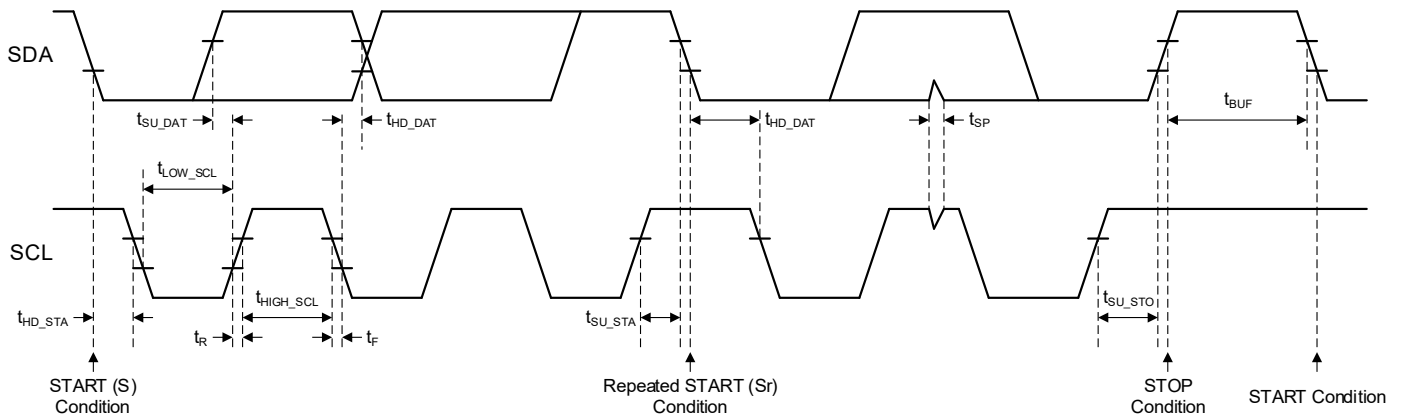
SYMBOL	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{HD_STA}	START hold time ⁽²⁾		0.6			μs
t_{BUF}	Bus free time between a START and STOP condition ⁽²⁾		1.3			ms
t_{SU_STO}	Set-up time for a STOP condition ⁽²⁾		0.6			μs
t_R	SCL and SDA rising time ⁽²⁾		$20 + 0.1 \times C_B$		300	ns
t_F	SCL and SDA falling time ⁽²⁾		$20 + 0.1 \times C_B$		300	ns
t_{SP}	Pulse width of suppressed spike ⁽²⁾		0		50	ns
C_B	Capacitance bus for each bus line ⁽²⁾				400	pF

(1) Matching is defined as the difference between the maximum to minimum current divided by 2 times the average current.

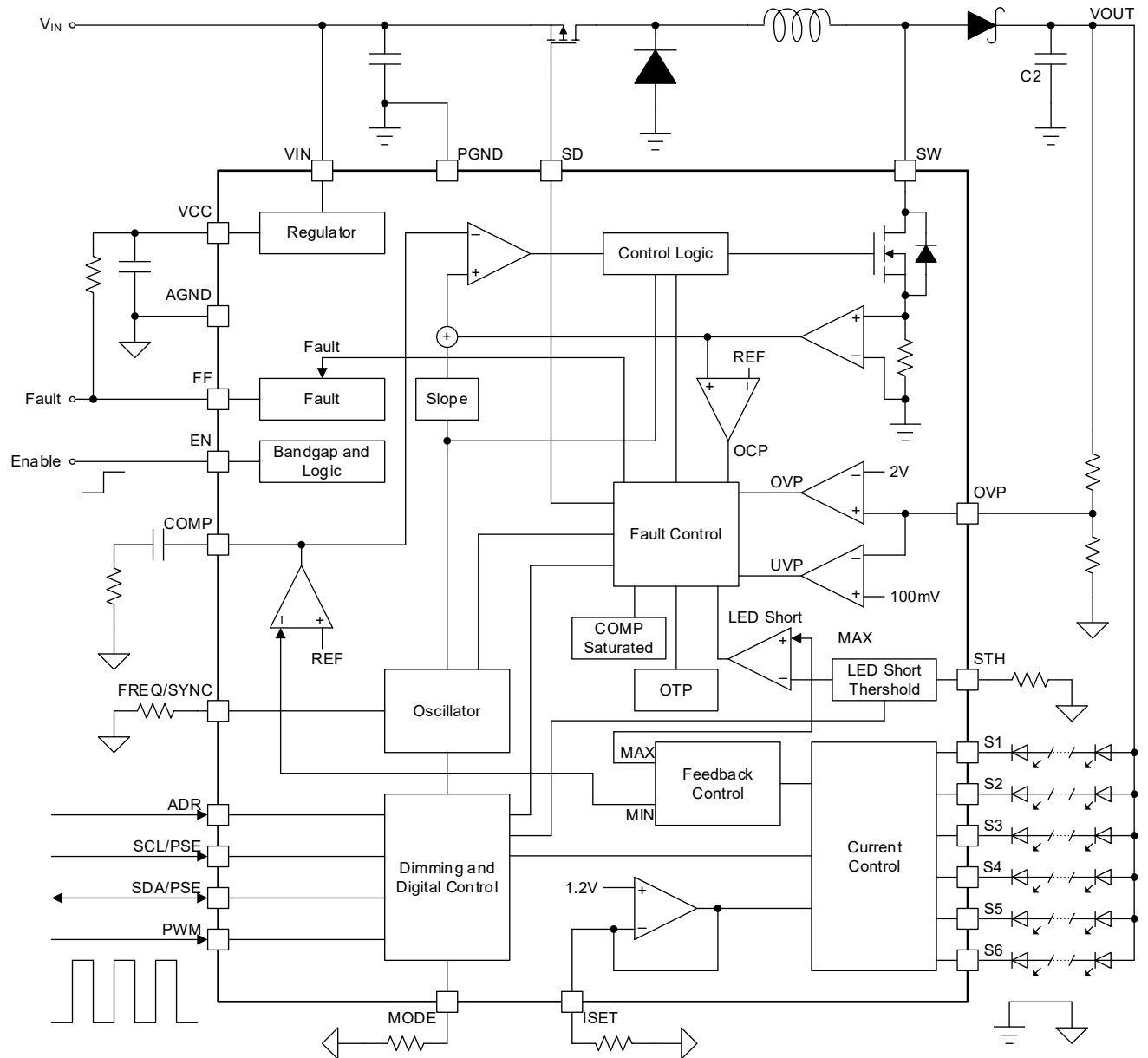
(2) Not tested in production. Specification guaranteed by design.

I2C Serial-Interface Timing Diagram

The LPQ3337 device communicates through a standard 2-wire I2C serial-interface to receive data in slave mode. The bus consists of a data line (SDA) and a clock line (SCL) with pull-up structures. A master device, usually a microcontroller or a digital signal processor, controls the I2C bus. Below figure shows the I2C interface timing diagram.



13. Functional Block Diagram



14. Detailed Description

14.1 Overview

The LPQ3337 device is a high-voltage LED driver for automotive infotainment, clusters, HUD and other automotive display LED backlight applications. The LPQ3337 integrated low side NMOS with 100 mΩ on resistance. The PWM input is used for brightness control by default. Alternatively, the brightness can also be controlled by I2C Interface.

The LPQ3337 is a configurable, fixed frequency, peak current mode step-up converter with up to six channels of regulated current sinks to drive an array of white LEDs. The LED current drivers provide up to 150mA per output and can be tied together to support higher current LEDs.

The internal error amplifier monitors the difference between the feedback voltage and the reference voltage, forming a closed-loop control system to regulate the boost output voltage. To get best efficiency, the boost voltage is adapted automatically to the minimum necessary level needed to drive the LED strings by monitoring the output voltage of S1 to S6 continuously. The switching frequency of the boost regulator can be set between 200kHz to 2.2MHz. The LPQ3337 can also control a power-line FET to reduce battery leakage when disabled and provide isolation and protection in the event of a fault.

14.2 Internal 5V Regulator

The LPQ3337 includes an internal linear regulator (VCC). When VIN exceeds 6V, this regulator outputs a 5V power supply to the internal MOSFET switch gate driver and the internal control circuitry. The VCC voltage drops to 0V when the chip shuts down. The chip remains disabled until VCC exceeds the under-voltage lockout (UVLO) threshold.

14.3 System Start-Up

When enabled, the LPQ3337 checks the topology connection. The device draws current from the SD pin to turn on the P-channel MOSFET if it is used (see Simplified Schematic). After a 500μs delay, the device monitors the OVP pin to see if the output is shorted to GND. If the OVP voltage is below 100mV, the device is disabled, and it latches off. The LPQ3337 then continues to check other safety limits (e.g. LED open, over-voltage protection). If all protection tests pass, the device starts boosting the step-up converter with an internal soft start.

The recommended start-up sequence is listed below:

1. VIN
2. EN
3. I2C (optional)
4. PWM dimming signal

14.3.1 State Machine Diagram

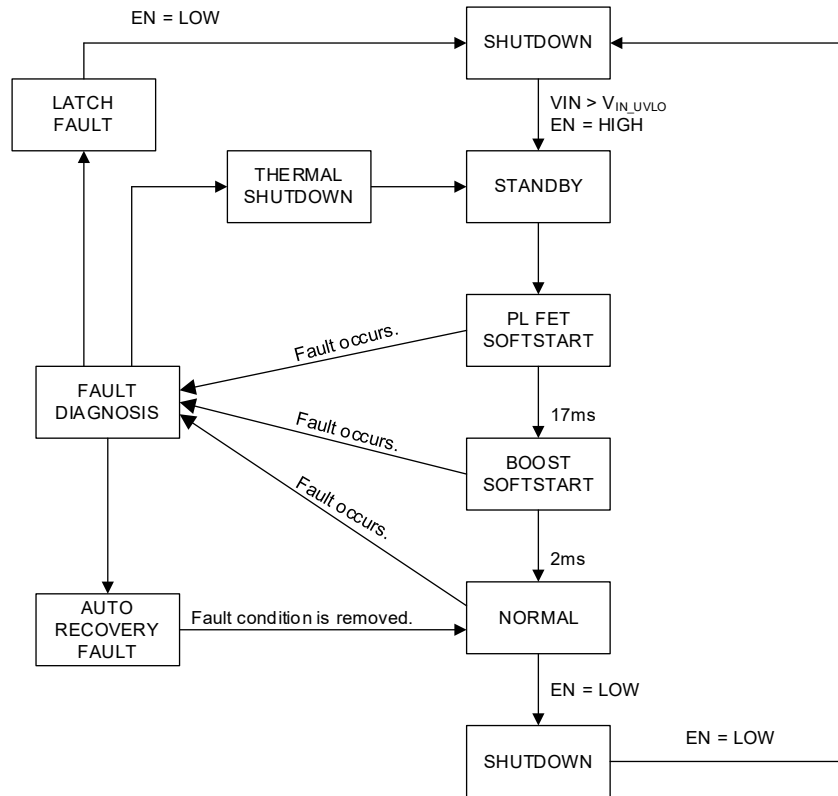


Figure 1 State Machine Diagram

14.3.2 Mode Description

SHUTDOWN

When EN is pulled low, the LPQ3337 device is in shutdown mode, the boost, the power-line FET, and the LED S1 to S6 outputs are turned off.

STANDBY

When VIN voltage is above V_{IN_UVLO} and the EN voltage turns from low to high, the LPQ3337 device enters the standby mode. The internal 5V voltage regulator is started up, all the configurations are loaded, and all the external resistors are detected.

In this mode, the I2C interface is accessible, the device can be accessed with I2C to change any configuration registers.

PL FET SOFTSTART

If there's no fault, the power-line FET is enabled and turned on gradually. The input and output capacitors of the boost are charged to the VIN level.

BOOST SOFTSTART

Boost voltage is ramped up to the initial boost voltage level with current limit in 17ms. In this mode, all the boost faults diagnoses are now enabled.

NORMAL

After 2ms from the BOOST SOFTSTART mode, the LED drivers are enabled when the brightness is greater than zero. In this mode, all the LED faults diagnoses are active.

FAULT Diagnosis

The LPQ3337 device has two types of faults diagnoses:

LATCH FAULT:

- Short LED driver output S1 to S6 to ground protection
- Short boost output VOUT to ground protection
- Latch-off current limit protection

When a latch fault occurs, the SD pin is pulled high to turn off the external P-channel MOSFET. The boost output VOUT is disconnected from VIN, and the device latches off. Only toggling the EN pin voltage can restart this device.

AUTO RECOVERY FAULT:

- Open LED string protection
- Short LED string protection
- Cycle-by-cycle current limit protection
- Over-temperature LED current decrement
- Thermal Protection

When an auto recovery fault occurs, the LPQ3337 device will continuously detect the operating condition. If the fault scenario is removed, the device will turn to NORMAL mode and operating as normal.

14.4 Step-Up Converter

The LPQ3337 employs peak current mode control to regulate the output power. At the beginning of each switching cycle, the internal clock turns on the internal N-channel MOSFET. In normal operation, the minimum turn-on time is about 100ns. A stabilizing ramp is added to the output of the current-sense amplifier to prevent sub-harmonic oscillations for duty cycles exceeding 50%. This result is fed into the PWM comparator. When the summed voltage reaches the output voltage of the error amplifier, the internal MOSFET turns off.

The output voltage of the internal error amplifier is an amplified signal of the difference between the reference voltage and the feedback voltage. The converter automatically chooses the lowest active voltage of S1 to S6 pin to provide a sufficient output voltage to power all the LED arrays.

If the feedback voltage drops below the reference voltage, the output of the error amplifier increases. Then more current flows through the MOSFET, which increases the power delivered to the output. This forms a closed loop that regulates the output voltage.

During light-load operation (e.g. when V_{OUT} is almost equal to V_{IN}), the converter runs in pulse-skip mode. In this mode, the MOSFET turns on for a minimum on time, then the converter discharges the power to the output for the remaining period.

14.5 Dimming Control

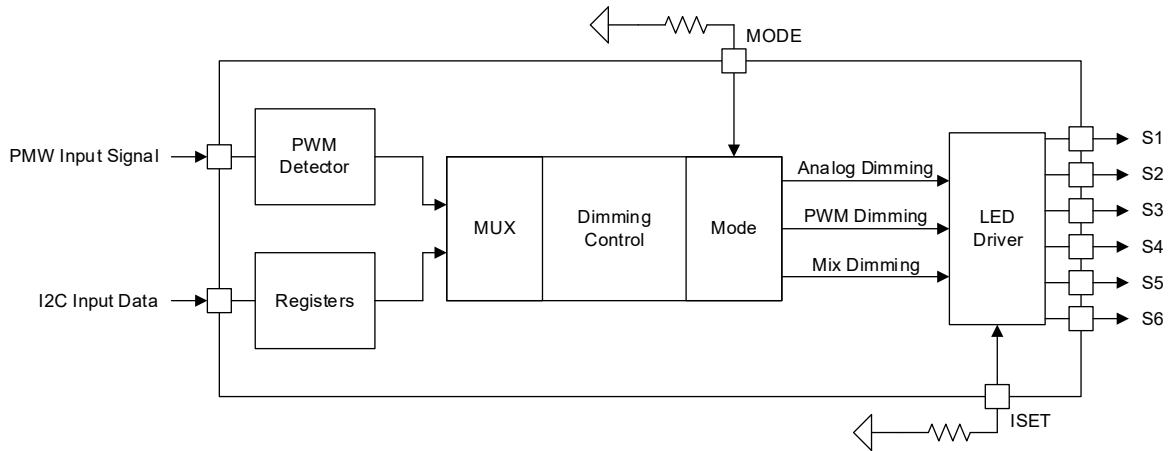


Figure 2 Dimming Control

The LPQ3337 implement two dimming control methods: PWM input signal dimming control and I2C input data dimming control. The MUX uses the internal register bit DIM_IN in the Dimming Setting Register (0x04) to select the dimming control method.

- By default (DIM_IN = 0), the PWM input signal dimming control method is selected after device starts up. With this method, the maximum dimming ratio is as high as 15000:1 at the PWM frequency at 200Hz.
- By setting DIM_IN = 1, the dimming control method switches to I2C input data dimming control method. With this method, there is a total of 16-bit dimming resolution. Write data to the Brightness LSB Register (0x05) and the Brightness MSB Register (0x06) to adjust the LED brightness directly.

14.6 Dimming Mode

The LPQ3337 provides three dimming modes: mix dimming mode, PWM dimming mode, and analog dimming mode. The different dimming mode can be selected by connecting a suitable resistor from the MODE pin to ground or via the I2C interface. The MODE pin voltage can be calculated with the Equation 1:

$$V_{MODE}(mV) = 18(\mu A) \times R_{MODE}(k\Omega) \quad (1)$$

Where V_{MODE} is the MODE pin voltage, and R_{MODE} is the resistor at the MODE pin.

14.6.1 Mix Dimming Mode

There are two methods to set the LPQ3337 device to work in the mix dimming mode with an either 25% or 12.5% transfer point (selected through the internal register).

- The first method is to connect a resistor from the MODE pin to ground and set the MODE pin voltage to a low level (<0.3V).
- The second method is to float the MODE pin and set the internal mode selection register bit MODE[1:0] to 00 through the I2C interface.

Apply a PWM dimming signal to the PWM pin. When the PWM dimming signal duty cycle exceeds 25% (MIXTP=0) or 12.5% (MIXTP=1), the device uses analog dimming, and the LED current amplitude follows the PWM signal duty cycle. When the PWM dimming signal duty cycle is below 25% (MIXTP=0) or 12.5% (MIXTP=1), the device uses PWM dimming (see below figure). The LED current amplitude remains at 1/4 of the full-scale current, and the output dimming duty is 4 times the duty of the input PWM dimming signal.

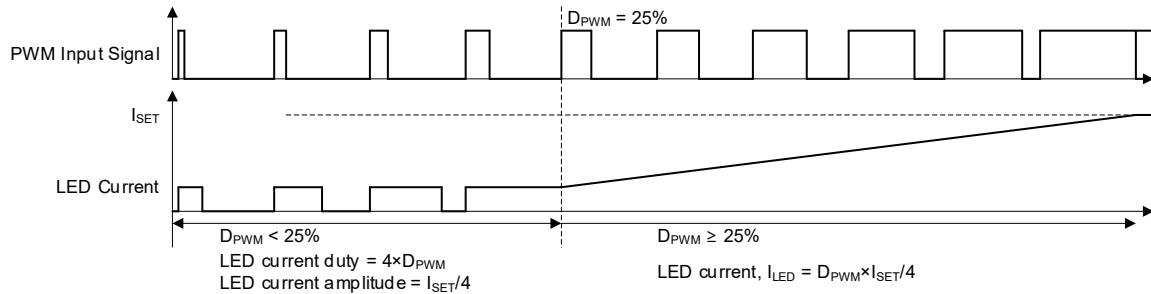


Figure 3 Mix Dimming Mode with 25% Transfer Point

There are two options for the output dimming frequency when the device uses mix dimming: 200Hz (default), or 23kHz (no audible noise, but larger minimum dimming duty). The output dimming frequency does not change with the input PWM dimming frequency. The output dimming frequency is selected with the mix dimming output frequency selection bit MIXFR through the I2C interface. This function eliminates audible noise and improves the dimming performance when there is a small dimming ratio.

14.6.2 Direct PWM Dimming

There are two methods to set the LPQ3337 device to work in the direct PWM dimming mode:

- The first method is to connect a resistor from the MODE pin to ground to set the MODE pin voltage to a middle level (0.5V to 0.8V)
- The second method is to float the MODE pin and set the internal mode selection register bit MODE[1:0] to 01 through the I2C interface.

When a PWM signal is applied to the PWM pin, the amplitude of the LED current remains at the LED full-scale, and the LED current is determined by the input PWM signal. The LED current duty cycle follows the PWM input signal duty cycle, and the LED current frequency is the same as the PWM input signal.

14.6.3 Analog Dimming Mode

There are two methods to set the LPQ3337 device to work in the analog dimming mode:

- The first method is to connect a resistor from the MODE pin to ground to set the MODE pin voltage to a high level (1V to 1.3V)
- The second method is to float the MODE pin and set the internal mode selection register bit MODE[1:0] to 10 through the I2C interface.

The PWM input signal is calculated by an internal counter. The amplitude of the LED current is equal to $I_{SET} \times D_{P_{WPM}}$, where I_{SET} is the full-scale LED current, and $D_{P_{WPM}}$ is the duty cycle of the PWM input signal. To improve analog dimming performance, a PWM input signal between 100Hz and 20kHz is recommended. Analog dimming supports a 200:1 dimming ratio.

14.6.4 Deep Dimming Ratio for PWM Dimming

When the output dimming on time is shorter than $7\mu s$, the output voltage VOUT is regulated to be 93% of the OVP voltage (see below figure).

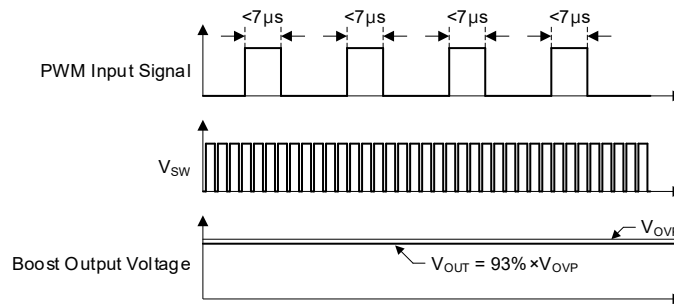


Figure 4 Deep Dimming Ratio for PWM Dimming

14.6.5 Phase Shift Function

To reduce the inrush current and eliminate the audible noise during the PWM dimming mode, the LPQ3337 employs a phase shift function.

There are two methods that can be used to enable the phase shift function.

- The first method is to connect the SCL/PSE pin and the SDA/PSE pin together and set the voltage of them between 0.75V and 1V.
- The second method is to set the internal register bit PSE to 1 through the I2C interface.

The current of each LED channel is phase shifted when the device uses the PWM dimming mode. The shifted phase depends on the number of active LED channels, and it can be estimated with Equation 2:

$$Phase = \frac{360^\circ}{n} \tag{2}$$

Where n is the number of active LED channels. If all six channels are in use, the shifted phase is 60°. LED1 directly follows the internal calculated PWM signal PWM_IN, and LED2 lags 60° behind (see below figure).

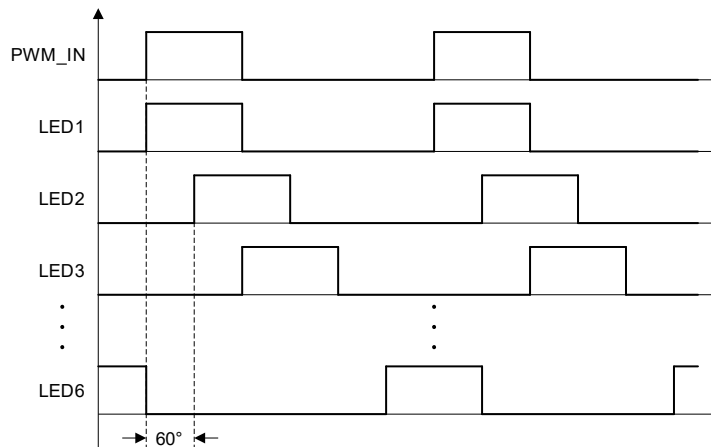


Figure 5 Phase Shift with 6 Channels

Below figure shows the phase shift function when four channels are used. In this case, the phase shift is 90°.

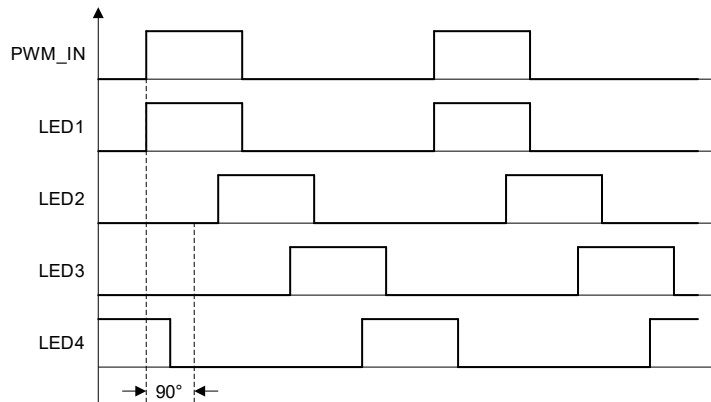


Figure 6 Phase Shift with 4 Channels

In phase shift operation, the channels must be disabled in descending order of channel number. For example, if three strings are employed in an application, then channels 6, 5, and 4 are disabled.

When using the phase shift function, two or more channels connecting to a single LED string is prohibited due to potential current imbalance risks.

14.6.6 Sloper

An optional sloper function makes the transition from one brightness value to another optically smoothly. By default, the advanced sloper is enabled with a 200mS linear sloper duration. Transition time between two brightness values is programmed with the internal register bits SLOPE_SELECT in the Dimming Setting Register (0x04).

With the advanced sloper enabled, the brightness changes are further smoothed to be more pleasing to the human eye. Advanced slope is programmed with the internal register bit ADV_SLOPE in Dimming Setting Register (0x04).

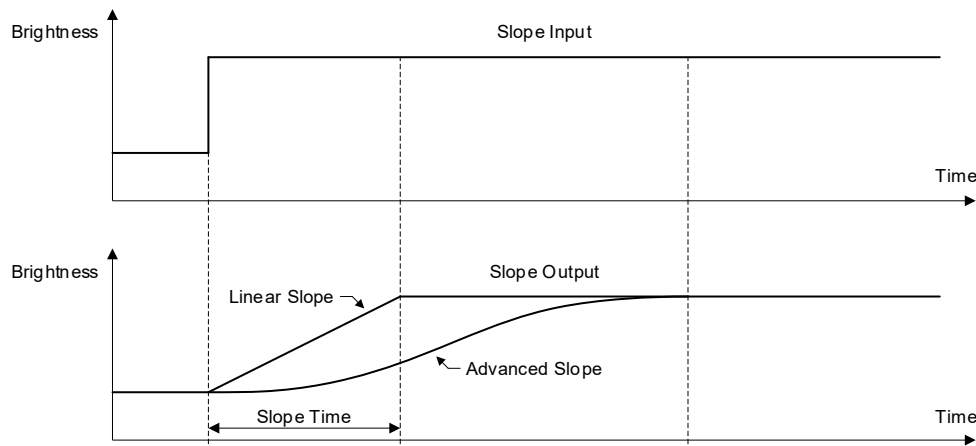


Figure 7 Brightness Sloper

14.7 Unused LED Channel Setting

If an unused LED current sink pin is connected to ground, the LPQ3337 can automatically detect it and remove it from the control loop during start-up. For example, if five strings are used, connect the S6 pin to ground. If four strings are used, connect the S5 pin and the S6 pin to ground.

The LPQ3337 can also disable the unused string via the internal register bits CH[2:0] as below:

- CH[2:0] = 000: All 6 channels are in use.
- CH[2:0] = 001: The initial 5 channels (channel 1 to channel 5) are in use.
- CH[2:0] = 010: The initial 4 channels (channel 1 to channel 4) are in use.

- CH[2:0] = 011: The initial 3 channels (channel 1 to channel 3) are in use.
- CH[2:0] = 100: The initial 2 channels (channel 1 and channel 2) are in use.
- CH[2:0] = 101: Only the first channel (channel 1) is in use.

14.8 Frequency Spread Spectrum

The LPQ3337 uses switching frequency jitter to spread the switching frequency spectrum. This reduces the spectrum spikes around the switching frequency and its harmonic frequencies.

The frequency jitter range is set by the internal register bit FSPR as below:

- When FSPR = 0 (default), the jitter frequency is 1/10 of the switching frequency.
- When FSPR = 1, the jitter frequency is 1/16 of the switching frequency.

The modulation frequency is set by the internal register bits FSPMF[1:0] as below:

- When FSPMF[1:0] = 00, the modulation frequency is 1/100 of the switching frequency.
- When FSPMF[1:0] = 01 (default), the modulation frequency is 1/150 of the switching frequency.
- When FSPMF[1:0] = 10, the modulation frequency is 1/200 of the central frequency.
- When FSPMF[1:0] = 11, the function is disabled.

14.9 Protections

The LPQ3337 provides open LED protection, short LED protection, S1 to S6 pin short-to-ground protection, over-current protection, VOUT short-to-ground protection, and thermal protection. If a protection is triggered, FF is pulled to GND, and the corresponding fault bit is set to 1. After the device recovers from a protection, FF is pulled high after a 750μs delay.

14.9.1 Open LED Protection

Open string protection is achieved by detecting the voltage on the OVP pin and the S1 to S6 pins. If one string is open during normal operation, the respective LED current sink pin voltage drops low to ground, and the device keeps charging the output voltage until it reaches the over-voltage protection threshold.

If over-voltage protection has been triggered, the chip stops switching and marks off the fault string, which has a voltage below 100mV on the corresponding LED current sink pin. The remaining LED strings force the output voltage back into normal regulation. The string with the largest voltage drop determines the output regulated voltage value. Every 500μs, the string that was marked sends a 10μs pulse current to check whether the open fault has been removed. This means that open string protection is recoverable.

14.9.2 Short LED String Protection

The LPQ3337 monitors the LED current sink pin voltages to determine whether a short string fault has occurred. If one or more strings are shorted, the corresponding LED current sink pins tolerate a high voltage stress. If any LED current sink pin voltage exceeds the short protection threshold, an internal counter starts.

If the fault condition lasts for 7.7ms ($D_{PWM} = 100\%$), the fault string is marked off. Once a string is marked off, it disconnects from the output voltage loop until the short is removed.

There are two methods to set the short protection threshold.

- The first method is to connect a resistor from the STH pin to ground. STH outputs an 18μA current source. The short protection threshold is 10 times the voltage on the STH pin. The threshold (V_{STH}) can be calculated with below Equation 3:

$$V_{STH_TH}(V) = 10 \times 18(\mu A) \times R_{STH}(k\Omega) \quad (3)$$

- The second method is to set the internal register bits TH_S[1:0] when the STH pin is floating.

If the LED current sink pin voltage on all used pins exceeds the threshold for 480ms ($D_{PWM} = 100\%$), all strings are marked off. The LPQ3337 remains on standby until the strings are released from the short condition. This function can be enabled or disabled through the internal register bit SEN.

Every 500μs, the string that was marked off sends a 10μs pulse current to check if the short fault is removed. This means that short string protection is recoverable.

14.9.3 S1 to S6 Short-to-Ground Protection

If any LED current sink pin is shorted to ground, the COMP voltage increases and saturates. If COMP is saturated for 40ms, this protection is triggered. The FF pin pulls low, and the SD pin pulls high to turn off the external P- channel MOSFET. After that, the device latches off.

14.9.4 VOUT Short-to-Ground Protection

If VOUT is shorted to ground, the output voltage decreases. If the voltage on the OVP pin reaches the under-voltage lockout (UVLO) threshold for 10μs, this protection is triggered. The SD pin pulls high to turn off the external P-channel MOSFET. VOUT disconnects from VIN, and the device latches off.

14.9.5 Cycle-by-Cycle Current Limit

To prevent the external components from exceeding the current stress rating, the LPQ3337 has cycle-by-cycle current limitation protection. If the output current exceeds the current limit value, the device stops switching until the next clock cycle.

14.9.6 Latch-Off Current Limit Protection

The device can be damaged by extreme conditions, such as an inductor or diode short to GND. To avoid this, the LPQ3337 provides the latch-off current limit protection. If the current flowing through the internal MOSFET reaches **7.5A** and lasts for 5 switching cycles, the latch-off current limit protection is triggered.

14.9.7 Over-Temperature LED Current Decrement

To prevent the device from operating at exceedingly high temperatures, the LPQ3337 implements thermal protection by detecting the junction temperature.

If the junction temperature exceeds 140°C, the LPQ3337 automatically reduces the LED current amplitude (see below figure). The LED current reduction range could be set with the internal register bits OT_RATIO in the Dimming Setting Register (0x04). By default, the current reduction is 10%, and it can be set to 20% by write OT_RATIO = 1.

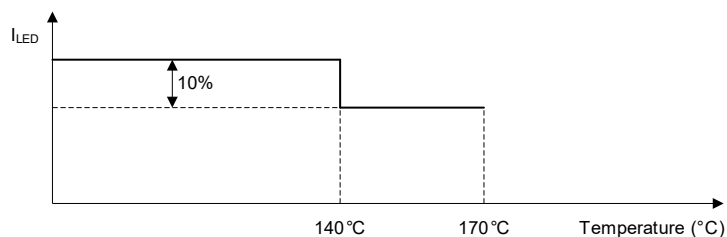


Figure 8 LED Current Decrement

This function is controlled by the internal register bit OTID (over-temperature current decrement) as below:

- When OTID = 0 (default), the over- temperature current decrement function is disabled.
- When OTID = 1, the over-temperature current decrement function is enabled.

14.9.8 Thermal Shutdown

If the junction temperature exceeds the protection upper threshold (T_{ST}), the device shuts down. When the temperature drops below the lower threshold, the device recovers. The hysteresis value is about 20°C.

15. I2C Interface

15.1 I²C Address

The 7-bit MSB device address is 0x38~0x3A. This address can be selected by connecting a resistor from the ADR pin to ground. The ADR pin's internal pull-up current is 18μA. When the ADR pin is floating, the device address is 0x38. When ADR < 0.4V, the device address is 0x3A. When ADR is between 0.4V and 1.4V, the device address is 0x39.

Table 1 LPQ3337 I2C Address

ADR Pin Voltage	LPQ3337 I2C Address
Floating	0x38
0 to 0.4V	0x3A
0.4V to 1.4V	0x39

After the start condition, the I2C master device sends a 7-bit address followed by an eighth read (1) or write (0) bit. The eighth bit indicates the register address to or from which the data will be written/read. The below figure shows an I2C-compatible device address.

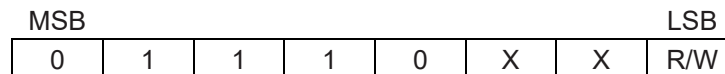


Figure 9 D907 I2C Address Format

15.2 Register Map

Below table lists the memory-mapped registers. If using the internal registers, float the corresponding pins.

Table 2 Register Map

Register Name	Description	Address (Hex)	Default Value
FUNCTION_SET1	Function Setting Register 1	0x00	0x06
FUNCTION_SET2	Function Setting Register 2	0x01	0x28
FAULT	Fault Register	0x02	0x00
DEV_ID	Device ID Register	0x03	0x00
DIM_SET	Dimming Setting Register	0x04	0x68
BRT_LSB	Brightness LSB Register	0x05	0x00
BRT_MSB	Brightness MSB Register	0x06	0x00

15.3 Function Setting Register 1

Address: 0x00				
Bits	Bit Name	Access	Default	Description
7	OTID	R/W	0	Enable the over-temperature LED current decrement function. 0: Disabled 1: Enabled
6:5	MODE	R/W	00	Select the dimming mode. Float the MODE pin if this register is used. 00: Mix dimming mode 01: PWM dimming mode 10: Analog dimming mode 11: Reserved
4	MIXTP	R/W	0	Select the mix dimming mode transfer point. 0: 25% transfer point 1: 12.5% transfer point
3	MIXFR	R/W	0	Select the mix dimming output frequency. 0: 200Hz 1: 23kHz
2:1	FSPMF	R/W	11	Select the frequency spread spectrum modulation frequency. 00: 1/100 of the switching frequency 01: 1/150 of the switching frequency 10: 1/200 of the switching frequency 11: Disable the frequency spread spectrum function
0	FSPR	R/W	0	Select the frequency spread spectrum jitter range. 0: 1/10 of the central frequency 1: 1/16 of the central frequency

15.4 Function Setting Register 2

Address: 0x01				
Bits	Bit Name	Access	Default	Description
7	PSE	R/W	0	Enable the phase shift function. 0: Phase shift disabled 1: Phase shift enabled
6:5	TH_S	R/W	01	Set the LED short protection threshold. 00: 2.5V 01: 5V 10: 7.5V 11: 10V
4:3	FSW	R/W	01	Set the switching frequency. Float the FREQ/SYNC pin if this register is used. 00: 200kHz 01: 400kHz 10: 1MHz 11: 2.2MHz
2:0	CH	R/W	000	Channel selection bits. 000: All 6 channels are in use. 001: The initial 5 channels (channel 1 to channel 5) are in use. 010: The initial 4 channels (channel 1 to channel 4) are in use. 011: The initial 3 channels (channel 1 to channel 3) are in use. 100: The initial 2 channels (channel 1 and channel 2) are in use. 101: Only the first channel (channel 1) is in use. 110, 111: Reserved.

15.5 Fault Register

Address: 0x02				
Bits	Bit Name	Access	Default	Description
7	SEN	R/W	0	Short all LED string protection enable bit. 0: Disabled 1: Enabled Note: Keep LED short protection by default. Only configure all LED protection at this bit.
6	DISABLE_IC	R/W	0	Disable the IC control bit. 0: The IC is enabled 1: The IC is disabled
5	FT_LEDG	R	0	S1 to S6 short-to-ground protection indication bit. If any LED current sink pin is short to ground, the fault bit is set to 1 until a power reset occurs. 0: No LED current sink pin short fault has occurred. 1: An LED current sink pin short fault has occurred.
4	FT_OTP	R	0	Over-temperature protection (OTP) fault indication bit. If an over-temperature fault occurs, the fault bit is set to 1 until a readback or power reset occurs. The fault status latches off. If the fault is removed, it is reset to 0 after this bit is read. 0: No OT fault has occurred. 1: An OT fault has occurred.
3	FT_UVP	R	0	Output under-voltage protection (UVP) fault indication bit. If a under-voltage fault occurs, the fault bit is set to 1 until a power reset occurs. 0: No UV fault has occurred. 1: A UV fault has occurred.
2	FT_OCP	R	0	Output over-current protection (OCP) fault indication bit. If an over-current fault occurs, the fault bit is set to 1 until a-power reset occurs. 0: No OC fault has occurred. 1: An OC fault has occurred.
1	FT_LEDS	R	0	LED short fault indication bit. If an LED short fault occurs, the fault bit is set to 1 until a readback or power reset occurs. Once this bit is read, the fault status cannot latch off until it is set to 0. 0: No LED short fault has occurred. 1: An LED short fault has occurred.
0	FT_LEDO	R	0	LED open fault indication bit. If an LED open fault occurs, the fault bit is set to 1 until a readback or power reset occurs. Once this bit is read, the fault status cannot latch off until it is set to 0. 0: No LED open fault has occurred 1: An LED open fault has occurred

15.6 Device ID Register

Address: 0x03				
Bits	Bit Name	Access	Default	Description
7:6	RESERVED	-	00	Reserved.
5:0	ID	R	000000	Device ID bits.

15.7 Dimming Setting Register

Address: 0x04				
Bits	Bit Name	Access	Default	Description
7	DIM_IN	R/W	0	External PWM input or I2C register input for brightness control selection bit. 0h = Brightness controlled by PWM input 1h = Brightness controlled by I2C register input
6	ADV_SLOPE	R/W	1	Advance sloper function selection bit. 0h = Linear Sloping 1h = Advanced Sloping
5:3	SLOPE_SELECT	R/W	5h	Linear brightness sloper duration set bit. 0h = Disable 1h = 1ms 2h = 2ms 3h = 50ms 4h = 100ms 5h = 200ms 6h = 300ms 7h = 500ms Times are for linear slope mode. Advanced sloper will increase durations while adding additional smoothing to brightness transitions. 1ms and 2ms sloper times are intended to be used only in linear mode. 50ms to 500ms sloper durations may be used with or without advanced sloper function.
2	OT_RATIO	R/W	0	Over-temperature LED current reduction ratio set bit. 0h = 10% 1h = 20%
1:0	RESERVED	-	00	Reserved.

15.8 Brightness LSB Register

Address: 0x05				
Bits	Bit Name	Access	Default	Description
7:0	BRT_LSB	R/W	00000000	Brightness code LSB

15.9 Brightness MSB Register

Address: 0x06				
Bits	Bit Name	Access	Default	Description
7:0	BRT_MSB	R/W	00000000	Brightness code MSB

16. Application Information

The D907 device is designed for automotive applications, and an input voltage VIN is intended to be directly connected to the vehicle battery. The device integrates a 5V linear regulator, and the logic control blocks are internally powered by the regulator. The device has flexible configurability through external components or by an I2C interface. The following sections show a design example of the LPQ3337 typical application.

16.1 Typical Application

Figure 11 shows a typical application schematic of the LPQ3337 in the display backlighting applications. It supports 6 LED strings with an automatic 60° phase shift. Each channel supports a maximum output current of 150mA. Both the PWM dimming and register dimming through the I2C interface are implemented to flexible control the brightness.

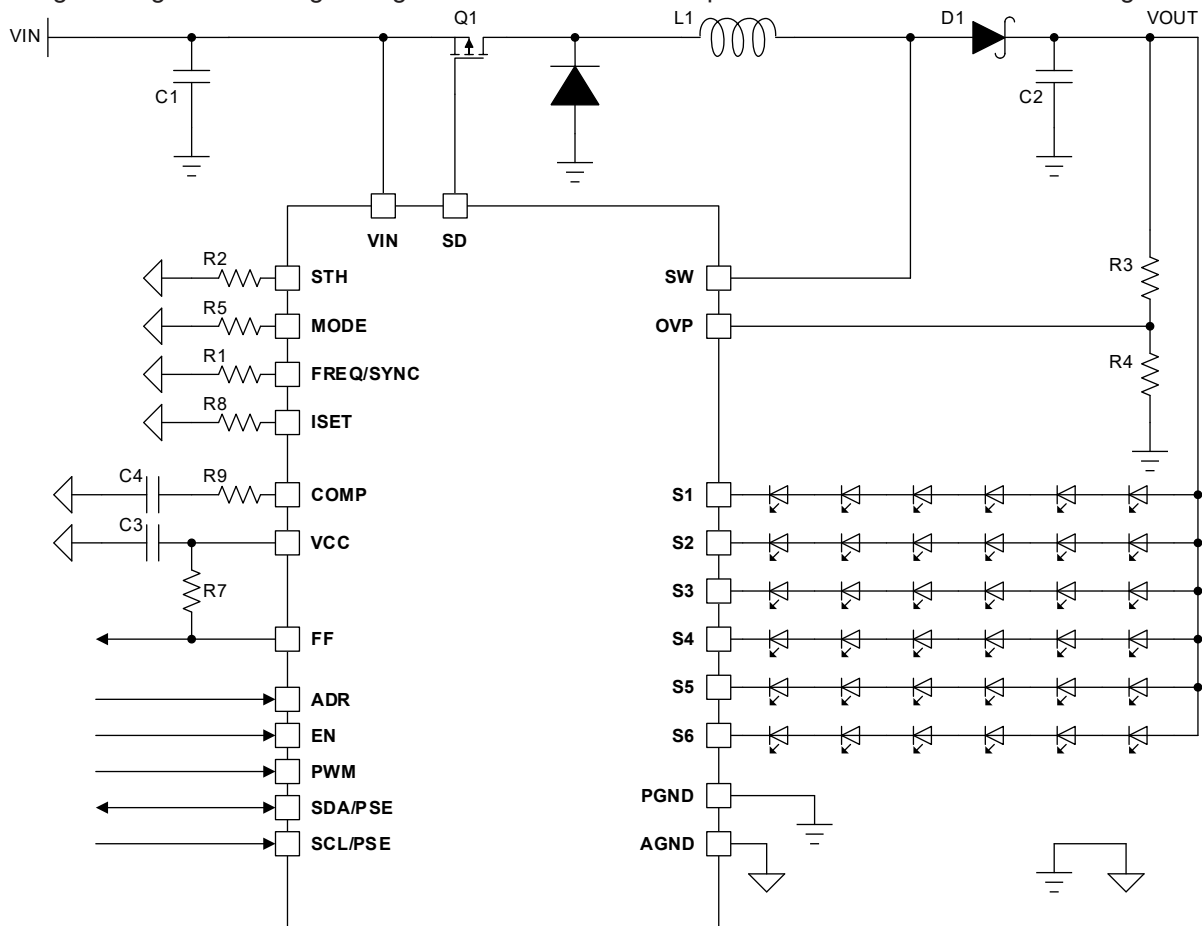


Figure 10 Typical Application Schematic

16.2 Design Procedure

16.2.1 Design Requirements

Table 3 illustrates a typical design requirement of the LED backlight application. According to this table, the following sections show the detailed design procedure.

Table 3 Design Requirements

Design Parameter	Value
VIN voltage range	5V to 20V
LED strings configuration	6 strings, 6 LEDs in series
Brightness control	I2C
Output configuration	OUT1 to OUT6 are in phase shift mode (60°)
LED string current	50mA
Boost frequency	400kHz
Inductor	22μH at 6.5A saturation current
R _{ISENSE} resistor	20mΩ
Power-line FET	Enabled
Input capacitors	10μF ceramic
Output capacitors	10μF ceramic
Spread spectrum	Enabled

16.2.2 LED Current Setting

The LED current amplitude is set by an external resistor connected from the ISET pin to ground. The LED current amplitude can be calculated with Equation 4:

$$I_{LED}(mA) = \frac{1245}{R_{ISET}(k\Omega)} \quad (4)$$

For example, if R_{ISET} = 24.9kΩ, the LED current is 50mA.

16.2.3 Switching Frequency

The switching frequency can be configured by an external resistor, I2C interface, or the external clock. To configure the frequency with an external resistor on FREQ/SYNC, the switching frequency can be estimated with Equation 5:

$$f_{SW}(kHz) = \frac{22000}{R_{FREQ}(k\Omega)} \quad (5)$$

For example, if R_{FREQ} = 44.2kΩ, the switching frequency is set to 500kHz.

If setting the switching frequency via the I2C interface, float the FREQ/SYNC pin. The register bits FSW[1:0] have the following options:

- 00: 200kHz
- 01: 400kHz
- 10: 1MHz
- 11: 2.2MHz

16.2.4 Selecting the Input Capacitor

The input capacitor reduces the surge current drawn from the input supply, as well as the switching noise from the device. Use ceramic capacitors with X5R or X7R dielectrics due to their low ESR and small temperature coefficients. For most applications, a 10μF ceramic capacitor is sufficient.

16.2.5 Selecting the Inductor

The LPQ3337 requires an inductor to supply a higher output voltage while being driven by the input voltage. A larger-value inductor results in less ripple current, lower peak inductor current, and less stress on the internal N-channel

MOSFET. However, a larger-value inductor has a larger physical size, higher series resistance, and lower saturation current.

Choose an inductor that does not saturate under the worst-case load conditions. Select the minimum inductor value to ensure that the boost converter works in continuous conduction mode (CCM) with high efficiency and good EMI performance. Calculate the required inductance value using Equation 6:

$$L \geq \frac{\eta \times V_{OUT} \times D \times (1 - D)^2}{2 \times f_{SW} \times I_{LOAD}} \quad (6)$$

Where V_{OUT} is the output voltage, I_{LOAD} is the LED load current, η is the efficiency, f_{SW} is the switching frequency, and D can be estimated with Equation 7:

$$D = 1 - \frac{V_{IN}}{V_{OUT}} \quad (7)$$

Where V_{IN} is the input voltage.

With the given inductor value, the inductor DC current rating should be at least 40% greater than the maximum input peak inductor current for most applications. The inductor's DC resistance should be as small as possible for higher efficiency.

16.2.6 Selecting the Output Capacitor

The output capacitor keeps the output voltage ripple small and ensures feedback loop stability. Ceramic capacitors with X7R dielectrics are recommended for their low-ESR characteristics. For most applications, a 10 μ F ceramic capacitor is sufficient.

16.2.7 Selecting the Over-Voltage Protection Threshold (OVP)

Open string protection is achieved by monitoring the voltage on the OVP pin. An LED string failure can result in the feedback voltage dropping to 0. If this occurs, the LPQ3337 continues boosting the output voltage until it reaches the configured OVP threshold. Then OVP is triggered.

Select appropriate values for the OVP pin's resistor divider to set the OVP threshold. The recommended OVP threshold is about 1.1 to 1.2 times the output voltage under normal operation.

The OVP threshold can be estimated with Equation 8:

$$V_{OVP} = 2 \times \left(1 + \frac{R_{OVP_HIGH}}{R_{OVP_LOW}} \right) \quad (7)$$

Where R_{OVP_HIGH} is the OVP pin's high-side resistor, and R_{OVP_LOW} is the OVP pin's low-side resistor.

16.3 Layout Guidelines

Careful attention must be given to the PCB layout and component placement. Efficient placement of the high frequency switching path is critical to prevent noise and electromagnetic interference. For the best results, refer to Figure 12 and follow the guidelines below:

1. Connect the IC's exposed pad to the AGND pin and ensure that all logic signals are referred to AGND.
2. Externally connect PGND to AGND. Route PGND away from the logic signals.
3. Keep the loop between the SW and PGND pin, output diode (D1), and capacitors (C1 and C2) as short as possible due to the high-frequency pulse current.

17. Revision History

Revision	Date	Change Description
Rev 0.1	11/06/2024	Initial Release
Rev 0.2	12/21/2024	<ul style="list-style-type: none"> ● Add description: If MODE is connected to a resistor, registers can't configure dimming mode. ● Keep ESD level ● Cycle-by-cycle current limiting@25C is 2.6A, Cycle-by-cycle current limiting by temp range is 2.3A, current limit protection 7.5A ● OT reduction ratio is 10% or set to 20% by register0x04 bit[2] OT_RATIO ● Add register0x04 bit[2] OT_RATIO, default 0H 10%, 1H 20% ● Remove section14.6.4 Deep Dimming Ratio for PWM Dimming ● Add section14.3.1 State Machine diagram ● Add section14.3.2 Mode Description ● Add section 14.3.3 start up sequence ● Change the description of FT_OTP in REG 0x02 bit[4]
Rev 0.3	12/25/2024	<ul style="list-style-type: none"> ● Change the Over-Temperature LED Current Decrement algorithm
Rev 0.4	03/10/2025	<ul style="list-style-type: none"> ● Adjusted some sentences and word formatting. ● Updated schematics, timing diagrams, block diagrams, and other figures ● Changed ICL Current limit protection typical value to 6A ● Added PWM_PD PWM pull-down resistance in the spec table ● Changed "LEDx" to "S1 to S6. ● Updated the content of the dimming mode section. ● Corrected the addresses corresponding to BRT_LSB and BRT_MSB in the register map. ● Added content to the dimming control section.
Rev 0.5	03/18/2025	<ul style="list-style-type: none"> ● Updated Section 14.3.1 State Machine Diagram and 14.3.2 Mode Description ● Changed the title of Section 15 from "Application Information" to "I2C Interface" ● Updated the default value of 15.3 Function Setting Register1 from "0x02" to "0x06" ● Added Section 16. Application Information
Rev 0.6	08/19/2025	<ul style="list-style-type: none"> ● Update Reg0X02 bit[7], keep LED short protection by default. Only configure all LED protection at this bit. ● Update REG 0X02, if LEDG/UVP/SCP events occur, the fault bit is set to 1 until a power reset occurs.