1. Features

- AEC-Q100 qualified for automotive applications:
  - Device temperature grade 1:
  - -40°C to 125°C, T_A
  - Device HBM ESD classification level 2
  - Device CDM ESD classification level C4B
- Input voltage operation range 4.2V to 48V
- Six high-precision current sinks
  - Up to 200mA DC current for each current sink
  - Current matching 1% (typical)
  - Dimming ratio 32000:1 using 152-Hz LED output PWM frequency
  - Up to 16-bit LED dimming resolution with I2C or PWM input
  - 8 configurable LED strings configuration
- Auto-phase shift PWM dimming
- 12-bit analog dimming
- Up to 48-V V_{OUT} boost or SEPIC DC/DC controller
  - Switching frequency 100kHz to 2.2MHz
  - Boost spread spectrum for reduced EMI
  - Boost sync input to set boost switching frequency from an external clock
- Extensive fault diagnostics
- Available in 5mmX5mm QFN5X5-32 Package

2. Applications

- Backlight for:
  - Automotive infotainment
  - Automotive instrument clusters
  - Smart mirrors
  - Heads-up displays (HUD)

3. General Description

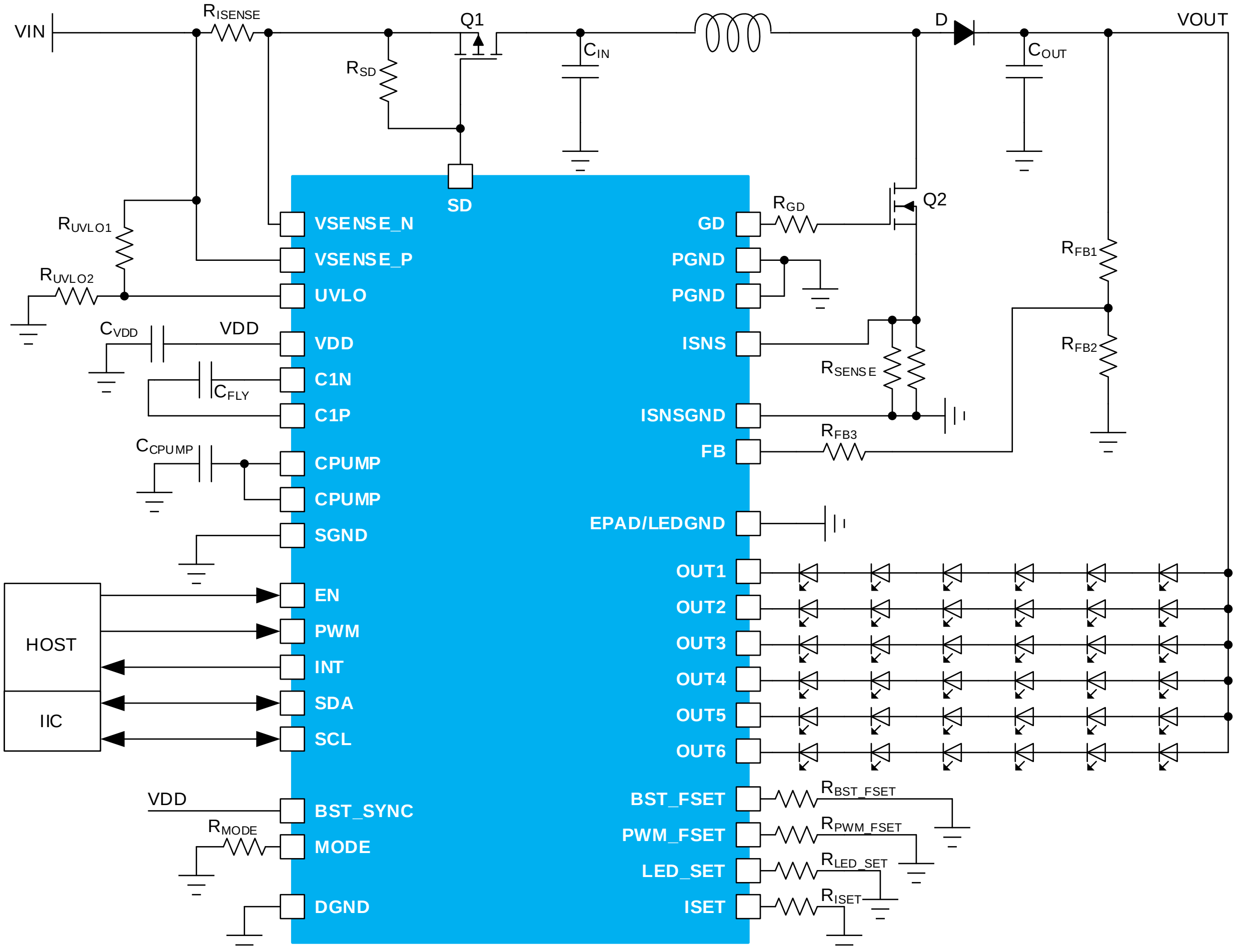
The LPQ3336 is an automotive high-efficiency LED driver with boost controller. The Six high precision current sinks support phase shifting that is automatically adjusted based on the number of channels in use. LED brightness can be controlled globally through the I2C interface or PWM input.

The boost controller integrates an adaptive boost output voltage control based on the headroom voltages of the LED current sinks. This feature minimizes power consumption by adjusting the boost voltage to the lowest sufficient level in all conditions. A wide-range adjustable frequency allows the LPQ3336 to avoid disturbance for AM radio band.

The LPQ3336 device supports built-in hybrid PWM dimming and analog current dimming, which reduces EMI, extends the LED lifetime, and increases the total optical efficiency.

4. Order Information

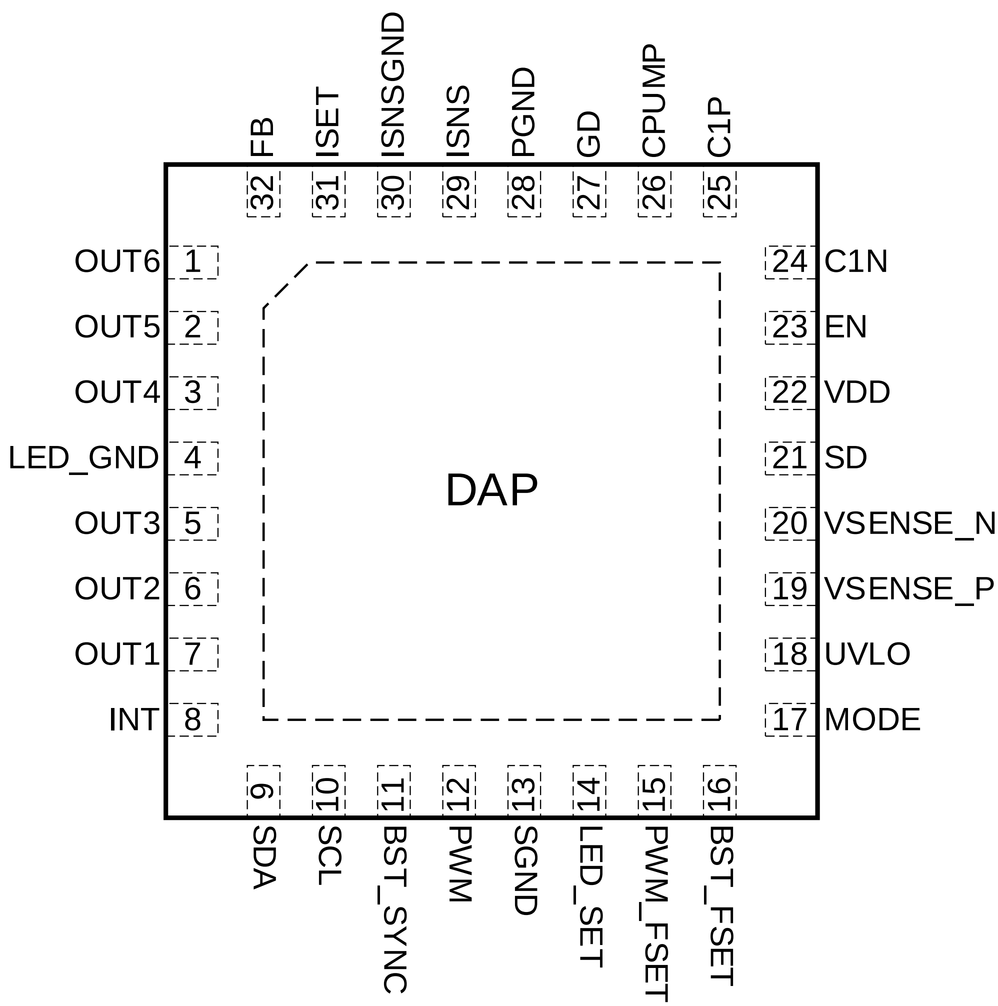
5. Simplified Schematic



6. Device Information

Part Number	Top Marking	Moisture Sensitivity Level	Package	Shipping
LPQ33XX	LPS LPQ33XX YWXA0	MSL3	QFN5X5-32	3K/REEL
Marking indication: Y: Year code. W: Week code. X: Batch numbers.				

7. Pin Diagram



LPQ33XX QFN5X5-32

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

8. Pin Description

Pin Number	Name	Description
1	OUT6	LED current sink output. If unused tie to ground.
2	OUT5	LED current sink output. If unused tie to ground.
3	OUT4	LED current sink output. If unused tie to ground.
4	LED_GND	LED string power ground.
5	OUT3	LED current sink output. If unused tie to ground.
6	OUT2	LED current sink output. If unused tie to ground.
7	OUT1	LED current sink output. If unused tie to ground.
8	INT	Device fault interrupt open-drain output. A 10-kΩ pullup resistor is recommended.
9	SDA	SDA for I2C interface. A 10-kΩ pullup resistor is recommended.
10	SCL	SCL for I2C interface. A 10-kΩ pullup resistor is recommended.
11	BST_SYNC	Input for synchronizing boost. When synchronization is not used, connect this pin to ground to disable spread spectrum or to VDD to enable spread spectrum.
12	PWM	PWM input for brightness control. Tie to GND if unused.
13	SGND	Signal ground.
14	LED_SET	LED string configuration through external resistor. Do not leave floating.
15	PWM_FSET	LED dimming frequency setup through external resistor. Do not leave floating.
16	BST_FSET	Boost switching frequency setup through external resistor. Do not leave floating.
17	MODE	Dimming mode setup through external resistor. Do not leave floating.
18	UVLO	Input voltage sense for programming input UVLO threshold through external resistor to VIN.
19	VSENSE_P	Pin for input voltage detection for OVP protection and positive input for input current sense.
20	VSENSE_N	Negative input for input current sense. If input current sense is not used, please tie to VSENSE_P pin.
21	SD	Power line FET control. Open Drain output. If unused, leave this pin floating.
22	VDD	Power supply input for internal analog and digital circuit. Connect a 10uF capacitor between the VDD pin to GND.
23	EN	Enable input.
24	C1N	Negative input for charge pump flying capacitor. If the feature is not used, leave this pin floating.
25	C1P	Positive input for charge pump flying capacitor. If the feature is not used, leave this pin floating.
26	CPUMP	Charge pump output pin. Connect to VDD if charge pump is not used. A 4.7uF decoupling capacitor is recommended on CPUMP pin.
27	GD	Gate driver output for external N-FET
28	PGND	Power ground.
29	ISNS	Boost current sense pin.
30	ISNSGND	Current sense resistor GND.
31	ISET	LED full-scale current setup through external resistor.
32	FB	Boost feedback input.
33	EPAD	LED ground connection.

9. Absolute Maximum Ratings (Note 1)

VSENSE_N, SD, UVLO to GND -- -0.3V to (VSENSE_P+0.3)V
VSENSE_P, FB to GND -- -0.3V to +52V
OUT1-OUT6 to GND --- -0.3V to +52V
C1N, C1P, VDD, EN, ISNS, ISNS_GND, INT, MODE to GND -- -0.3V to +6V
PWM_FSET, BST_FSET, LED_SET, ISET, GD, CPUMP to GND -- -0.3V to +6V
PWM, BST_SYNC, SDA, SCL to GND -- -0.3V to (VDD+0.3)V

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 (Note 2)

HBM (Human Body Model) AEC Q100-002 -- 3KV
MM (Machine Model) --- 300V
CDM (Charge Discharge Model) AEC-Q100-011 --- 800V

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

11. Thermal Information

Junction Temperature (T_J) -- 150°C
Operating Junction Temperature Range (T_J) -- -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

12. Recommended Operating Conditions

Over Operating free-air temperature range (unless otherwise noted) (Note 3)

PARAMETER		MIN	TYP	MAX	UNIT
VSENSE_P	VSENSE_P pin voltage	4.2	12	48	V
VSENSE_N	VSENSE_N pin voltage	4.2	12	48	V
SD	SD pin voltage	4.2	12	48	V
UVLO	UVLO pin voltage	4.2	12	48	V
FB	FB pin voltage	0		48	V
OUT1 to OUT6	OUT1 to OUT6 pin voltage	0		48	V
ISNS	ISNS pin voltage	0		5.5	V
ISNS_GND	ISNS_GND pin voltage	0		5.5	V
EN	EN pin voltage	0	3.3	5.5	V
PWM	PWM pin voltage	0	3.3	5.5	V
INT	INT pin voltage	0	3.3	5.5	V
SDA, SCL	SDA and SCL pin voltage	0	3.3	5.5	V
BST_SYNC	BST_SYNC pin voltage	0	3.3	5.5	V
VDD	VDD pin voltage	0	3.3/5	5.5	V
C1N, C1P	C1N and C1P pin voltage	0	5	5.5	V
CPUMP	CPUMP pin voltage	0	5	5.5	V
GD	GD pin voltage	0	5	5.5	V

Note 3: All voltages are with respect to the potential at the GND pins.

13. Functional Block Diagram

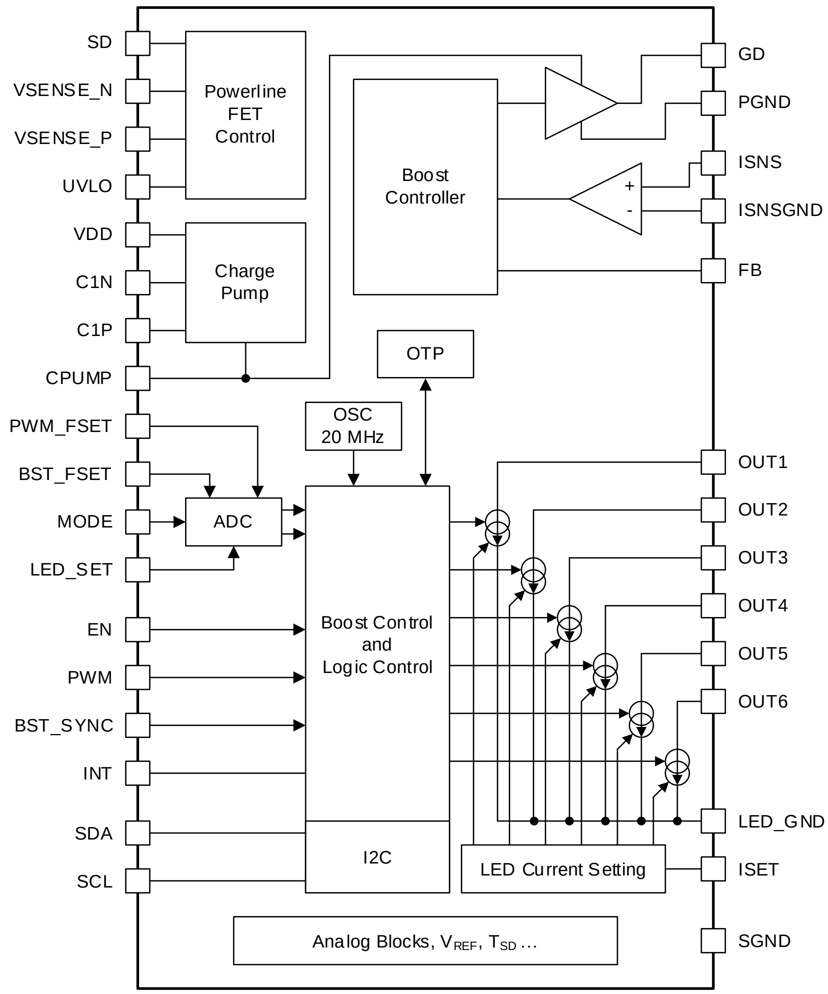


Figure 1 Functional Block Diagram

14. Typical Application Circuit

Channel	Topology Type	Package
6-channel LED	Boost	QFN5X5-32

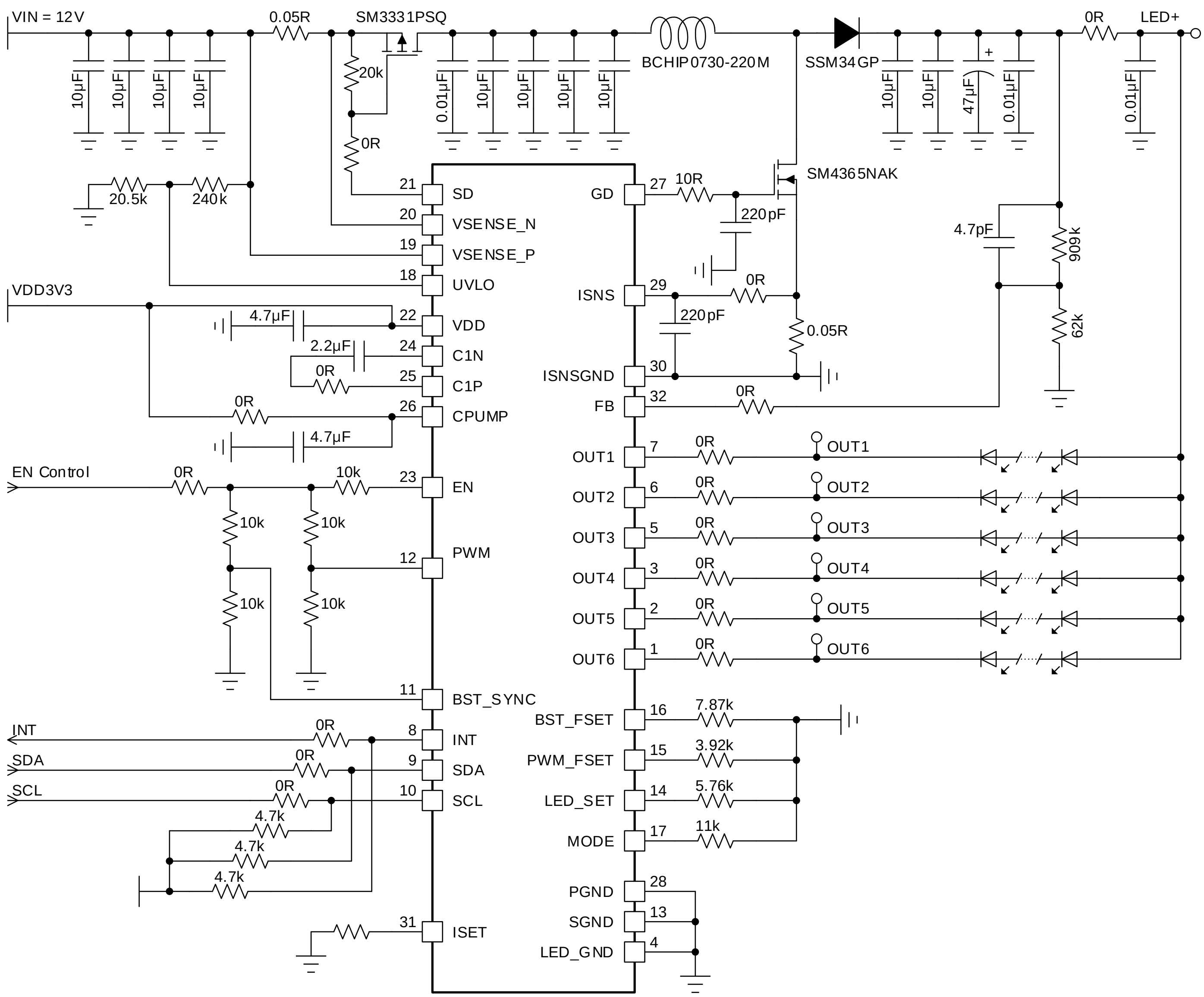


Figure 2 Typical Application Circuit of QFN5X5-32 Package

15. Detailed Description

The LPQ3336 device is a high-voltage LED driver for automotive infotainment, clusters, HUD and other automotive display LED backlight applications. PWM input is used for brightness control by default. Alternatively, the brightness can also be controlled by I2C Interface.

The boost frequency, LED PWM frequency, and LED string current are configured with external resistors through the BST_FSET, PWM_FSET, and ISET pins. The INT pin is used to report faults to the system. Fault interrupt status can be cleared through the I2C interface or be cleared on the falling edge of the EN pin.

The LPQ3336 device supports pure PWM dimming. The six LED current sink drivers provide up to 200mA per channel and can be tied together to support higher current LEDs. The maximum output current of the LED drivers is set with the ISET resistor and can be optionally scaled by the internal register bit LEDx_CURRENT[11:0] through the I2C interface. The LED output PWM frequency is set with a PWM_FSET resistor. The number of connected LED strings is configured by the LED_SET resistor, and the device automatically selects the corresponding phase shift mode. For example, if the device is set to 4-strings mode, each LED output is phase shifted by 90 degrees with each other (=360/4). Unused outputs, which must be connected to ground, will be disabled and excluded from adaptive boost voltage control loop and won’t generate more LED faults.

A resistor divider connected from VOUT to the FB pin sets the maximum boost voltage. For best efficiency, the boost voltage is adapted automatically to the minimum necessary level needed to drive the LED strings by monitoring all the LED output voltages continuously. The switching frequency of the boost regulator can be set between 100kHz and 2.2MHz by the BST_FSET resistor. The boost has a start-up feature that reduces the peak current from the power line during startup. The LPQ3336 can also control a power-line FET to reduce battery leakage when disabled and provide isolation and protection in the event of a fault.

Fault detection features of LPQ3336 include:

- Open-string and shorted LED detection
  - LED fault detection prevents system overheating in case of open or short in some of the LED strings
- LED short-to-ground detection
- ISET/BST_FSET/PWM_FSET/LED_SET/MODE resistor out-of-range detection
- Boost overcurrent
- Boost overvoltage
- Device undervoltage protection(VDD UVLO)
  - Threshold sensing from the VDD pin
- VIN input overvoltage protection(VIN OVP)
  - Threshold sensing from the VSENSE_P pin
- VIN input undervoltage protection(VIN UVLO)
  - Threshold sensing from the UVLO pin
- VIN input overcurrent protection(VIN OCP)
  - Threshold sensing across voltage between the VSENSE_P pin and the VSENSE_N pin
  - Thermal shutdown in case of die over temperature

16. Device Address Setting

Device Slave Address (0x2Ah)

MSB							LSB
0	1	0	1	0	1	0	R/W

Read Address	Write Address
0101,0101 (55h)	0101,0100 (54h)

Device Slave Address (0x28h)

MSB							LSB
0	1	0	1	0	0	0	R/W

Read Address	Write Address
0101,0001 (51h)	0101,0000 (50h)

Device Slave Address (0x2Bh)

MSB							LSB
0	1	0	1	0	1	1	R/W

Read Address	Write Address
0101,0111 (57h)	0101,0110 (56h)

Device Slave Address (0x29h)

MSB							LSB
0	1	0	1	0	0	1	R/W

Read Address	Write Address
0101,0011 (53h)	0101,0010 (52h)

17. Register Map

Below table lists the memory-mapped registers. All register offset addresses not listed in the table should be considered as reserved locations and the register contents should not be modified.

Table 1 Register Map

Name	Address	Default Value	Bits															
			15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BRT_CONTROL	0x00	0x0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LED_CURR_CONFIG	0x02	0x0FFF	-	-	-	-	1	1	1	1	1	1	1	1	1	1	1	1
USER_CONFIG1	0x04	0x08A3	-	0	0	0	1	0	0	0	1	0	1	0	0	0	1	1
USER_CONFIG2	0x06	0x0100	-	-	-	-	-	-	-	1	-	-	0	0	0	0	0	0
SUPPLY_INT_EN	0x08	0x2AAA	-	-	1	0	1	0	1	0	1	0	1	0	1	0	1	0
BOOST_INT_EN	0x0A	0xA028	1	0	1	0	0	0	0	0	0	0	1	0	1	0	-	-
LED_INT_EN	0x0C	0x00AA	-	-	-	-	-	-	-	-	1	0	1	0	1	0	1	0
SUPPLY_STATUS	0x0E	0x0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BOOST_STATUS	0x10	0x0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LED_STATUS	0x12	0x0000	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FSM_DIAGNOSTICS	0x14	0x0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PWM_INPUT_DIAGNOSTICS	0x16	0x0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PWM_OUTPUT_DIAGNOSTICS	0x18	0x0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LED_CURR_DIAGNOSTICS	0x1A	0x0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ADAPT_BOOST_DIAGNOSTIC	0x1C	0x0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AUTO_DETECT_DIAGNOSTIC	0x1E	0x0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

18. Registers settings

20.1 BRT_CONTROL Register

Address: 0x00h. Default Value: 0x0000h.

Bits	Name	Type	Default Value	Description
15:0	DISPLAY_BRT	R/W	0h	Display Brightness Register.

20.2 LED_CURR_CONTROL Register

Address: 0x02h. Default Value: 0x0FFFh.

Bits	Name	Type	Default Value	Description
15:12	RESERVED	R/W	0h	These bits are reserved.
11:0	LED_CURRENT	R/W	FFFh	LED current control for all LED outputs.

20.3 USER_CONFIG 1 Register

Address: 0x04h. Default Value: 0x08A3h.

Bits	Name	Type	Default Value	Description
15	RESERVED	R/W	0h	These bits are reserved.
14	SPREAD_PSEUDO_EN	R/W	0h	0h = Pseudo Random SS disable 1h = Pseudo Random SS enable
13:12	SPREAD_MOD_FREQ	R/W	0h	Boost spread spectrum modulation frequency. 0h = 200Hz 1h = 500Hz 2h = 800Hz 3h = 1.2kHz
11:10	SPREAD_RANGE	R/W	2h	OSC_BST spread spectrum range. 0h = 3.3% 1h = 4.3% 2h = 5.3% 3h = 7.2%
9:8	BRT_MODE	R/W	0h	Select the PWM pin or the DISPLAY_BRT register for brightness control. 0h = Brightness controlled by PWM input 1h = Reserved 2h = Brightness controlled by DISPLAY_BRT register 3h = Reserved
7:5	SLOPE_SELECT	R/W	5h	Select the duration for linear brightness sloper. 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 the brightness transition. 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.
4:2	DITHER_SELECT	R/W	0h	Dither mode select. 0h = Dither Disable 1h = 1-bit Dither 2h = 2-bit Dither 3h = 3-bit Dither 4h = 4-bit Dither
1:1	ADV_SLOPE_ENABLE	R/W	1h	0h = Linear Sloping 1h = Advanced Sloping
0:0	EN_MIN_PWM_LIMIT	R/W	1h	Allows PWM pulses to be dithered to reduce lower minimum brightness. 0h = Disable 1h = Enable

20.4 USER_CONFIG 2 Register

Address: 0x06h. Default Value: 0x0100h.

Bits	Name	Type	Default Value	Description
15:9	RESERVED	R/W	0h	These bits are reserved.
8	EN_LED_GND_DETECT	R/W	1h	Enable LED short-to-ground detection during the boost soft start and normal operation. 0h = Disable 1h = Enable
7:6	RESERVED	R/W	0h	These bits are reserved.
5	LED6_SHORT_DISABLE	R/W	0h	Disable LED string-6 internal short fault. 0h = Enable 1h = Disable
4	LED5_SHORT_DISABLE	R/W	0h	Disable LED string-5 internal short fault. 0h = Enable 1h = Disable
3	LED4_SHORT_DISABLE	R/W	0h	Disable LED string-4 internal short fault. 0h = Enable 1h = Disable
2	LED3_SHORT_DISABLE	R/W	0h	Disable LED string-3 internal short fault. 0h = Enable 1h = Disable
1	LED2_SHORT_DISABLE	R/W	0h	Disable LED string-2 internal short fault. 0h = Enable 1h = Disable
0	LED1_SHORT_DISABLE	R/W	0h	Disable LED string-1 internal short fault. 0h = Enable 1h = Disable

20.5 SUPPLY_INT_EN Register

Address: 0x08h. Default Value: 0x2AAAh.

Bits	Name	Type	Default Value	Description
15:14	RESERVED	R/W	0h	These bits are reserved.
13:12	BSTSYNC_INT_EN	R/W	2h	Missing boost sync interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
11:10	CP_INT_EN	R/W	2h	Charge pump interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
9:8	CPCAP_INT_EN	R/W	2h	Charge pump capacitor missing interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
7:6	VINOCP_INT_EN	R/W	2h	VIN over-current interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 2h = Disable interruption 3h = Enable interruption
5:4	VDDUVLO_INT_EN	R/W	2h	VDD under-voltage interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
3:2	VINOVP_INT_EN	R/W	2h	VIN over-voltage interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
1:0	VINUVLO_INT_EN	R/W	2h	VIN under-voltage interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption

20.6 BOOST_INT_EN Register

Address: 0x0Ah. Default Value: 0xA028h.

Bits	Name	Type	Default Value	Description
15:14	TSD_INT_EN	R/W	2h	Thermal shutdown interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
13:12	ISET_INT_EN	R/W	2h	ISET resistor short-to-ground interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
11:10	LEDSET_INT_EN	R/W	0h	Missing LEDSET resistor interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
9:8	MODE_INT_EN	R/W	0h	Missing MODE resistor interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
7:6	FSET_INT_EN	R/W	0h	Missing FSEL resistor interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
5:4	BSTOCP_INT_EN	R/W	2h	Boost over-current interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
3:2	BSTOVPH_INT_EN	R/W	2h	Boost over-voltage high interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
1:0	RESERVED	R/W	0h	These bits are reserved.

20.7 LED_INT_EN Register

Address: 0x0Ch. Default Value: 0x00Aah.

Bits	Name	Type	Default Value	Description
15:8	RESERVED	R/W	0h	These bits are reserved.
7:6	GLOBAL_INT_EN	R/W	2h	Global interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
5:4	IIC_ERROR_INT_EN	R/W	2h	IIC time out interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
3:2	INVSTRING_INT_EN	R/W	2h	Invalid LED string configuration interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption
1:0	LED_INT_EN	R/W	2h	LED open/internal short/short to GND interruption enable. Read: 0h = Interruption is currently disabled 2h = Interruption is currently enabled Write: 1h = Disable interruption 3h = Enable interruption

20.8 SUPPLY_STATUS Register

Address: 0x0Eh. Default Value: 0x0000h.

Bits	Name	Type	Default Value	Description
15	CRCERR_STATUS	R/W	0h	CRC error fault status. 0h = No fault 1h = Fault
14	CRCERR_CLEAR	R/W	0h	CRC error fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
13	BSTSYNC_STATUS	R/W	0h	Missing boost sync fault status. 0h = No fault 1h = Fault
12	BSTSYNC_CLEAR	R/W	0h	Missing boost fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
11	CP_STATUS	R/W	0h	The charge pump fault status. 0h = No fault 1h = Fault
10	CP_CLEAR	R/W	0h	The charge pump fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
9	CPCAP_STATUS	R/W	0h	Missing charge pump capacitor fault status. 0h = No fault 1h = Fault
8	CPCAP_CLEAR	R/W	0h	Missing charge pump capacitor fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
7	VINOCP_STATUS	R/W	0h	VIN over-current fault status. 0h = No fault 1h = Fault
6	VINOCP_CLEAR	R/W	0h	VIN over-current fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
5	VDDUVLO_STATUS	R/W	0h	VDD under-voltage fault status. 0h = No fault 1h = Fault
4	VDDUVLO_CLEAR	R/W	0h	VDD under-voltage fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
3	VINOVP_STATUS	R/W	0h	VIN over-voltage fault status. 0h = No fault 1h = Fault
2	VINOVP_CLEAR	R/W	0h	VIN over-voltage fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
1	VINUVLO_STATUS	R/W	0h	VIN under-voltage fault status. 0h = No fault 1h = Fault
0	VINUVLO_CLEAR	R/W	0h	VIN under-voltage fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.

20.9 BOOST_STATUS Register

Address: 0x10h. Default Value: 0x0000h.

Bits	Name	Type	Default Value	Description
15	TSD_STATUS	R/W	0h	Thermal shutdown fault status. 0h = No fault 1h = Fault
14	TSD_CLEAR	R/W	0h	Thermal shutdown fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
13	ISET_STATUS	R/W	0h	ISET resistor short-to-ground fault status. 0h = No fault 1h = Fault
12	ISET_CLEAR	R/W	0h	ISET resistor short to ground fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
11	LEDSET_STATUS	R/W	0h	Missing LED resistor fault status. 0h = No fault 1h = Fault
10	LEDSET_CLEAR	R/W	0h	Missing LED resistor fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
9	MODESEL_STATUS	R/W	0h	Missing MODE SEL resistor fault status. 0h = No fault 1h = Fault
8	MODESEL_CLEAR	R/W	0h	Missing MODE SEL resistor fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
7	FSET_STATUS	R/W	0h	Missing boost FSET resistor fault status. 0h = No fault 1h = Fault
6	FSET_CLEAR	R/W	0h	Missing boost FSET resistor fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
5	BSTOCP_STATUS	R/W	0h	Boost over-current fault status. 0h = No fault 1h = Fault
4	BSTOCP_CLEAR	R/W	0h	Boost over-current fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
3	BSTOVPH_STATUS	R/W	0h	Boost OVP high fault status 0h = No fault 1h = Fault
2	BSTOVPH_CLEAR	R/W	0h	Boost OVP high fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
1	BSTOVPL_STATUS	R/W	0h	Boost OVP low fault status. 0h = No fault 1h = Fault
0	BSTOVPL_CLEAR	R/W	0h	Boost OVP low fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.

20.10 LED_STATUS Register

Address: 0x12h. Default Value: 0x0000h.

Bits	Name	Type	Default Value	Description
15	RESERVED	R/W	0h	These bits are reserved.
14	IIC_ERROR_STATUS	R/W	0h	IIC time out fault status. 0h = No fault 1h = Fault
13	IIC_ERROR_CLEAR	R/W	0h	IIC time-out fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
12	INVSTRING_STATUS	R/W	0h	Invalid string configuration fault status. 0h = No fault 1h = Fault
11	INVSTRING_CLEAR	R/W	0h	Invalid string configuration fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
10	LED_STATUS	R/W	0h	LED open/internal short/short-to-ground fault status. 0h = No fault 1h = Fault
9	LED_CLEAR	R/W	0h	LED open/internal short/short-to-ground fault clear. Write 1 to both status bit and clear bit at the same time to clear the interruption register status and the interruption pin status.
8	GND_LED	R/W	0h	LED short-to-ground fault status. 0h = No fault 1h = Fault
7	SHORT_LED	R/W	0h	LED internal short status. 0h = No fault 1h = Fault Status is cleared with LED_STATUS bit.
6	OPEN_LED	R/W	0h	LED open fault status. 0h = No fault 1h = Fault Status is cleared with LED_STATUS bit.
5	LED6_FAULT	R/W	0h	LED string 6 status. 0h = No fault 1h = Fault
4	LED5_FAULT	R/W	0h	LED string 5 status. 0h = No fault 1h = Fault
3	LED4_FAULT	R/W	0h	LED string 4 status. 0h = No fault 1h = Fault
2	LED3_FAULT	R/W	0h	LED string 3 status. 0h = No fault 1h = Fault
1	LED2_FAULT	R/W	0h	LED string 2 status. 0h = No fault 1h = Fault
0	LED1_FAULT	R/W	0h	LED string 1 status. 0h = No fault 1h = Fault

20.11 FSM_DIAGNOSTICS Register

Address: 0x14h. Default Value: 0x0000h.

Bits	Name	Type	Default Value	Description
15:5	RESERVED	R/W	0h	These bits are reserved.
4:0	FSM_LIVE_STATUS	R/W	0h	Current state of the functional state machine. 0h = DISABLED 1h = LDO_STARTUP 2h = OTP_READ 3h = STANDBY 4h to Fh = BOOST_STARTUP 10h = NORMAL 11h = SHUTDOWN 12h = FAULT_RECOVERY 13h = ALL_LED_FAULT

20.12 PWM_INPUT_DIAGNOSTICS Register

Address: 0x16h. Default Value: 0x0000h.

Bits	Name	Type	Default Value	Description
15:0	PWM_INPUT_STATUS	R/W	0h	16-bit value for detected duty cycle of PWM input signal.

20.13 PWM_OUTPUT_DIAGNOSTICS Register

Address: 0x18h. Default Value: 0x0000h.

Bits	Name	Type	Default Value	Description
15:0	PWM_OUTPUT_STATUS	R/W	0h	16-bit value for configured duty cycle of PWM output signal.

20.14 LED_CURRENT_DIAGNOSTICS Register

Address: 0x1Ah. Default Value: 0x0000h

Bits	Name	Type	Default Value	Description
15:12	RESERVED	R/W	0h	These bits are reserved.
11:0	LED_CURRENT_STATUS	R/W	0h	12-bit current DAC code that brightness path is driving to OUT1 to OUT6.

20.15 ADAPT_BOOST_DIAGNOSTICS Register

Address: 0x1Ch. Default Value: 0x0000h.

Bits	Name	Type	Default Value	Description
15:11	RESERVED	R/W	0h	These bits are reserved
10:0	VBOOST_STATUS	R/W	0h	An 11-bit boost voltage code that the adaptive boost voltage control loop send to the analog boost block. In two-resistor method, the boost output voltage is $\left(1+\frac{R1}{R2}\right) \times 1.21V + R1 \times 18.9nA \times V_{BOOST\_STATUS}$

20.16 AUTO_DETECT_DIAGNOSTICS

Address: 0x1Eh. Default Value: 0x0000h.

Bits	Name	Type	Default Value	Description
15	RESERVED	R/W	0h	These bits are reserved.
14:12	AUTO_PWM_FREQ_SEL	R/W	0h	LED PWM frequency value from the PWM_SEL resistor detection 0h = 152Hz 1h = 305Hz 2h = 610Hz 3h = 1221Hz 4h = 2441Hz 5h = 4883Hz 6h = 9766Hz 7h = 19531Hz
11	RESERVED	R/W	0h	These bits are reserved.
10:8	AUTO_LED_STRING_CFG	R/W	0h	LED string configuration from the LED_SET resistor detection. 0h = 6 separate strings 1h = 5 separate strings 2h = 4 separate strings 3h = 3 separate strings 4h = 2 separate strings 5h = 6 channel outputs connected in 3 groups to drive 3 strings 6h = 6 channel outputs connected in 2 groups to drive 2 strings 7h = 6 channel outputs connected in 1 group to drive 1 string
7:6	RESERVED	R/W	0h	These bits are reserved.
5:3	AUTO_BOOST_FREQ_SEL	R/W	0h	Boost switching frequency value from the PWM_FSET resistor detection 0h = 100kHz 1h = 200kHz 2h = 303kHz 3h = 400kHz 4h = 500kHz 5h = 1818kHz 6h = 2000kHz 7h = 2222kHz
2:0	MODE_SEL	R/W	0h	LED dimming MODE value from MODE detection. 0h = PWM mode, IIC address 0x2B 1h = 12.5% hybrid dimming mode, IIC address 0x2B 2h = Constant current mode, IIC address 0x2B 3h = Direct PWM, IIC address 0x2B 4h = PWM mode, IIC address 0x2A 5h = 12.5% hybrid dimming mode, IIC address 0x2A 6h = Constant current mode, IIC address 0x2A 7h = Direct PWM, IIC address 0x2A

19. Application Information

The LPQ3336 device is designed for automotive applications, and an input voltage VIN is intended to be directly connected to the vehicle battery. Depending on the input voltage, the device may be used in either boost mode or SEPIC mode. The device is internally powered from the VDD pin, and voltage must be in 2.7V to 5.5V range. The device has flexible configurability through external components or by an I2C interface. If the VDD voltage is not high enough to drive an external NMOS gate, an internal charge pump must be used to power the gate driver (GD pin).

21.1 Typical Applications

21.1.1 Full Feature Application for Display Backlight

Figure 25 shows a full-feature application for the LPQ3336 device in a boost topology. It supports 6 LED strings in display mode, each at 150mA, with an automatic 60° phase shift. Brightness control register is used for LED dimming method through the I2C interface. The charge pump is enabled with a 400kHz boost switching frequency with spread spectrum.

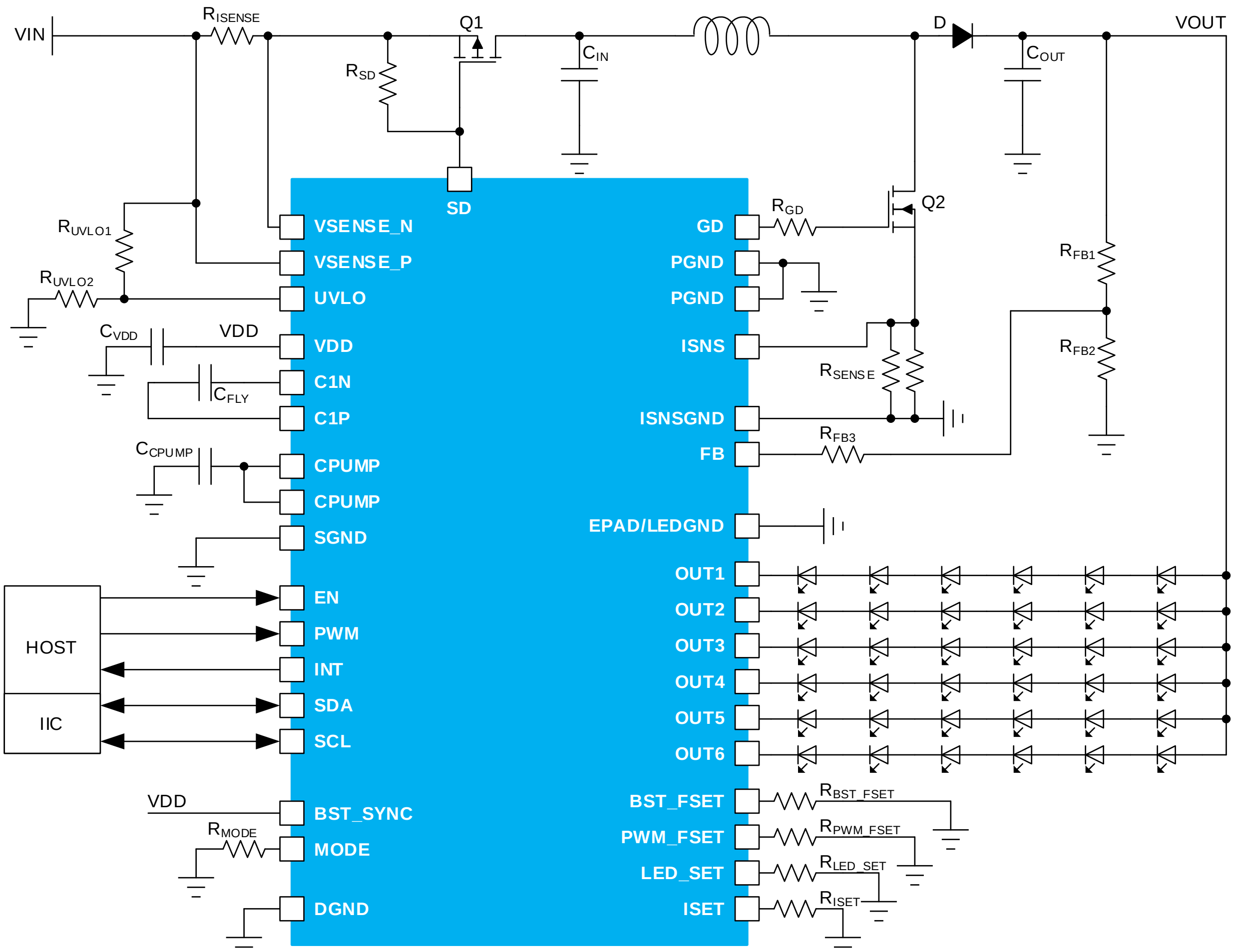


Figure 3 Full Feature Application for Display Backlight

21.1.1.1 Design Requirements

Table 13 illustrates a typical design requirement of the full-feature LED backlight application. According to this table, the following sections show the detailed design procedure.

Table 2 Full-Feature Application Design Requirements

Design Parameter	Value
VIN voltage range	5V to 20V
VDD voltage	3.3V
LED strings configuration	6 strings, 6 LEDs in series
Charge pump	Enabled
Brightness control	I2C
Output configuration	OUT1 to OUT6 are in phase shift mode (60°)
LED string current	150mA
Boost frequency	400kHz
Inductor	22µH at 6.5A saturation current
R_{ISENSE} resistor	20mΩ
Power-line FET	Enabled
R_{SENSE} resistor	30mΩ
Input capacitors	1 × 33µF Aluminum electrolytic, and 1 × 10µF ceramic
Output capacitors	1 × 33µF Aluminum electrolytic, and 1 × 10µF ceramic
Spread spectrum	Enabled

21.1.1.2 Inductor Selection

There are a few things to consider when choosing an inductor: inductance, current rating, and DC resistance (DCR). Shows the recommended inductance for each boost switching frequency. The LPQ3336 device automatically sets the internal boost compensation controls depending on the selected switching frequency.

Table 3 Recommended Inductance for Different Boost Switching Frequence

Switching Frequency (kHz)	Inductance (µH)
100	47
200	33
303	22
400	22
500	22
1818	10
2000	10
2222	10

The current rating of an inductor must be at least 25% higher than maximum boost switching current I_{SW_MAX}, which can be calculated with Equation 21. It is recommended to use an inductor with low DCR to reduce the power loss and achieve good efficiency. Efficiency varies with load condition, switching frequency, and components. 80% can be used as a typical estimation. 65% efficiency needs to be considered in extreme condition.

$$I_{SW\_MAX} = \frac{\Delta I_L}{2} + \frac{I_{OUT\_MAX}}{1-D} \quad (21)$$

where

- $\Delta I_L = \frac{VIN\_MIN \times D}{f_{SW} \times L}$
- $D = 1 - \frac{VIN\_MIN}{V_{OUT}} \times \eta$
- I_{SW_MAX} is the maximum switching current through the inductor
- ΔI_L is the inductor ripple current
- IOUT_MAX is the maximum output current of the boost converter

- D is the duty cycle of the boost converter
- VIN_MIN is the minimum input voltage of the boost converter
- f_{SW} is the minimum switching frequency of the boost converter
- L is the inductance of the boost converter
- V_{OUT} is the output voltage of the boost converter
- η is the efficiency of the boost converter

21.1.1.3 Output Capacitor Selection

There are a few things to consider when choosing an output capacitor: capacitance, voltage rating, and equivalent series resistance (ESR). Capacitance value determines voltage ripple and boost stability. The DC-bias effect can reduce effective capacitance significantly, by up to 80%, a consideration for capacitance value selection. The conservative target effective capacitance is 50µF to achieve good phase margin and gain margin. The voltage ratings of the output capacitor should be 50% greater than the maximum output voltage. It is recommended to use a 33µF or greater Aluminum electrolytic capacitor together with 10µF ceramic capacitors in parallel to reduce ripple, increase stability, and reduce ESR effect.

21.1.1.4 Input Capacitor Selection

It is recommended to use the same capacitor configurations as the output capacitors. Input capacitance can be reduced but must ensure enough filtering for input power.

21.1.1.5 Charge Pump Output Capacitor

It is recommended to use a ceramic capacitor with at least 10-V voltage rating as the charge pump output capacitor. A 10-µF ceramic capacitor can be used for most applications.

21.1.1.6 Charge Pump Flying Capacitor

It is recommended to use a ceramic capacitor with at least 10V voltage rating as the charge pump flying capacitor. A 2.2-µF capacitor connecting between the C1P pin and the C1N pin can be used for most applications.

21.1.1.7 Output Diode

A Schottky diode must be used for the boost output diode. The current rating must be at least 25% higher than the maximum output current. Schottky diodes with a low forward drop and fast switching speeds are ideal for increasing efficiency. At maximum output current, the forward voltage must be less than 0.5V, and the lower the better. The reverse breakdown voltage of the Schottky diode must be 25% greater than the output voltage. Do not use an ordinary rectifier diode, because the slow switching speed and the long recovery time will reduce efficiency and lead to poor load regulation.

21.1.1.8 Switching FET

Switching FET is a critical component that will determine the power efficiency of the boost converter. There are several aspects that need to be considered when selecting a switching FET: voltage rating, current rating, R_{DS_ON}, power dissipation, thermal resistance and rise/fall times. An N-MOSFET with at least 25% greater voltage rating than the maximum output voltage must be used. The current rating of switching FET should be the same or higher than inductor rating. R_{DS_ON} must be as low as possible, and less than 20mΩ is recommended. Thermal resistance (θ_{JA}) must also be low to dissipate heat from power loss on switching FET. In most cases, a resistor is suggested connecting between the GD pin and the gate of the switching FET. The resistor could be used to control the rising/falling time of the switching FET. This gate resistance could offer flexibility of balancing between EMC performance and efficiency.

21.1.1.9 Boost Sense Resistor

The R_{SENSE} resistor determines the boost over-current limit and is sensed every boost switching cycle. A high-power 20-mΩ resistor can be used for sensing the boost switching current and setting the maximum current limit at 10A (typical). R_{SENSE} can be increased to lower this limit and can be calculated with Equation 22. To avoid too much efficiency loss on R_{SENSE} resistor, the over-current limit is recommended to be set above 4A, therefore R_{SENSE} doesn't exceed 50mΩ. Power rating can be calculated from the inductor current and sense resistor resistance value.

$$R_{SENSE} = \frac{200mV}{I_{Boost\_OCP}} \quad (22)$$

where
- R_{SENSE} is the boost sense resistor
- I_{BOOST_OCP} is the boost over-current limit

21.1.1.10 Power-Line FET

The power-line FET is used to disconnect the boost input from the system input power supply to protect the device and boost components in case of an over-current event occurs. There are several aspects that need to be considered when selecting a switching FET: voltage rating, current rating, R_{DS_ON}. A P-MOSFET with at least 25% greater voltage rating than the maximum input voltage must be used as the power-line FET. Low R_{DS_ON} is important to reduce power loss on the FET, less than 20mΩ is recommended. The current rating for the PMOS must be at least 25% higher than input peak current. Minimum Gate-to-Source voltage (V_{GS}) to turn on transistor fully must be less than minimum input voltage. In most applications, it is suggested to use a 20kΩ resistor between the PMOS gate and source.

21.1.1.11 Input Current Sense Resistor

The input current-sense resistor (R_{ISENSE}) is used to sense the boost input current, and a high-power resistor is required. Over-current condition is detected when the voltage across R_{ISENSE} reaches 220mV. Typically, use a 20-mΩ sense resistor to set the current limit to 11A. Sense resistor value can be increased to lower over-current limit for application as needed. Power rating can be calculated from the input current and resistance value.

21.1.1.12 Feedback Resistor Divider

Feedback resistors R_{FB1} and R_{FB2} determine the maximum boost output voltage. Use Equation 23 to calculate the output voltage.

$$V_{BOOST\_MAX} = I_{SEL\_MAX} \times R_{FB1} + \left(\frac{R_{FB1}}{R_{FB2}} + 1\right) \times V_{REF} \quad (23)$$

Where
- V_{REF} = 1.21V
- I_{SEL_MAX} = 38.7uA
- R1/R2 normal recommended range is 7~15

21.1.2 Basic Operation Application

The LPQ3336 device needs only a few external components for basic functionality to get an extremely small PCB area and low BOM cost. In this example, the LPQ3336 device is configured with external components and no I2C communication. The power-line FET and the input-current sensing are also removed. The internal charge pump is not used, and all external synchronization functions and special features are disabled. The 33µF Aluminum electrolytic capacitor is removed for PCB area and height limitation, and boost external compensation is used to compensate the removal of the 33µF Aluminum electrolytic capacitor.

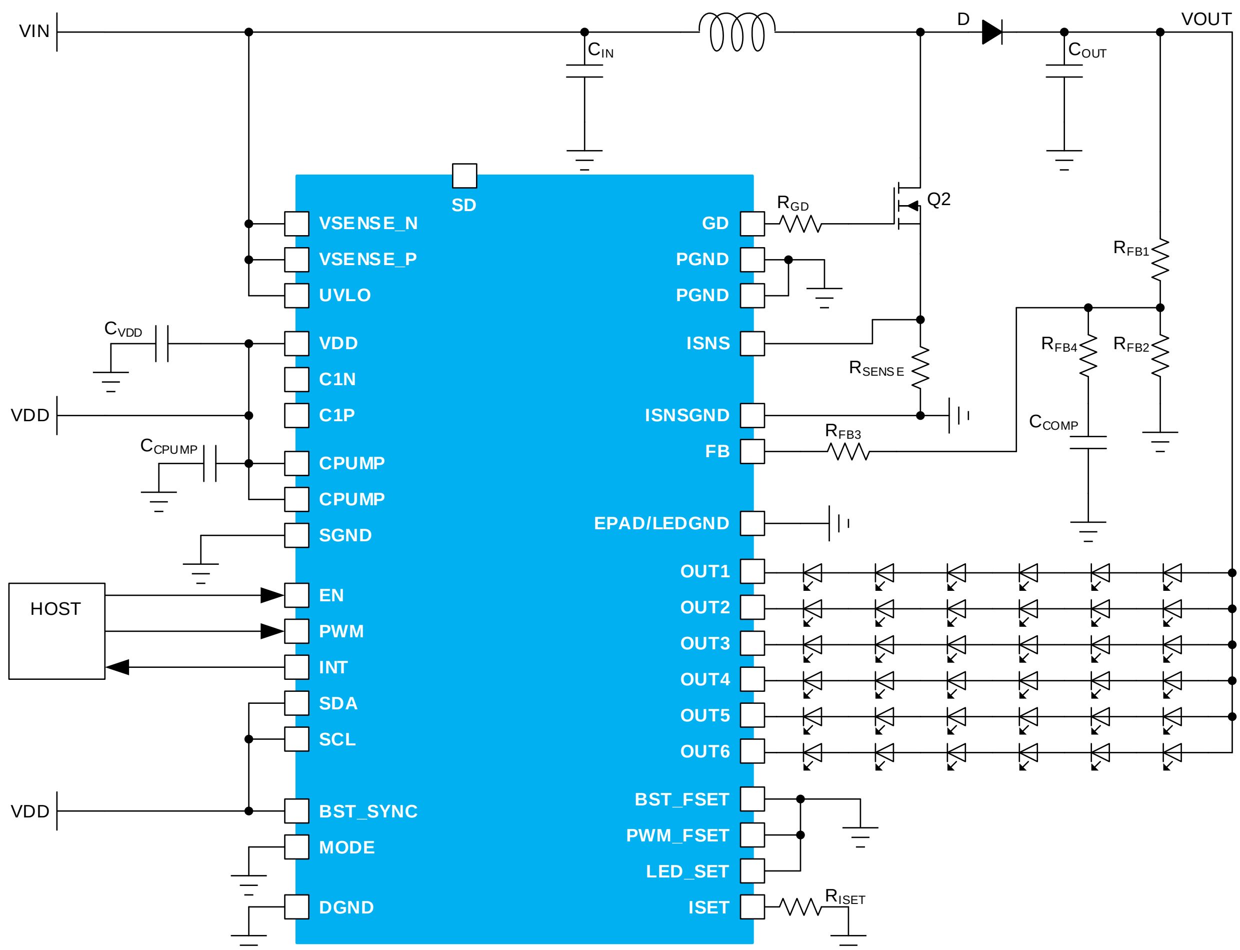


Figure 4 Basic Operation Application

For the external component selection, please refer to Section 21.1.1.

21.2 Power Supply Recommendations

The LPQ3336 is designed to operate with a vehicle battery. The VIN input must be protected from reverse polarity and load dump over 48V. The impedance of the input supply rail must be low enough that the inrush current does not cause the V_{IN} voltage to drop below the UVLO threshold. If long cables are used at the input power supply, additional bulk capacitance is required in addition to the normal input capacitor.
The voltage range for VDD is 3V to 5.5V. A ceramic capacitor must be placed as close as possible to the VDD pin. The boost gate driver is powered from the CPUMP pins. A ceramic capacitor must be placed to the CPUMP pins as close as possible.

21.3 Layout Guidelines

It is important that all the boost components must be near the converter and close to each other, and the high-current traces must be wide enough. The VDD power supply should be clean and low noise. A bypass capacitor to ground must be placed as close as possible at the VDD pin. The charge-pump capacitors must be placed close to the device. The charge-pump capacitors, the boost input capacitors, and the boost output capacitors must have closest vias to ground.
There are several main points to guide the PCB layout design:

- Current loops need to be minimized:
  - For low-frequency applications, the minimal current loop can be achieved by placing the boost components as close as possible to each other. Input and output capacitor grounds need to be close to each other to minimize current loop size.
  - Minimal current loops for high frequencies can be achieved by making sure that the ground plane is intact under the current traces. High frequency return currents follow the route with minimum impedance, which is the route with minimum loop area, not necessarily the shortest path. Minimum loop area is formed when return current flows just under the positive current route in the ground plane, if the ground plane is intact under the route.
  - For high-frequency applications, the copper area capacitance must be considered. For example, the copper area for the drain of boost N-MOSFET is a tradeoff between capacitance and the cooling capacity of the components.
- The ground plane must be intact under the high-current-boost traces to provide the shortest return path and smallest current loops for high frequencies.
- Route boost output voltage V_{OUT} to LEDs, and FB pin after output capacitors not straight from the diode cathode.
- FB network should be placed as close as possible to the FB pin, but not near the boost output.
- A small 39-pF bypass capacitor to ground could be placed close to the FB pin to suppress high frequency noise
- VDD line must be separated from the high-current supply path to the boost converter to prevent high frequency ripple affecting the device behavior.
- Capacitor connected to charge pump output CPUMP is recommended to have 10µF capacitance. This capacitor must be as close as possible to CPUMP pin. This capacitor provides a greater peak current for the gate driver and must be used even if the charge pump is disabled. If the charge pump is disabled, the VDD and CPUMP pins must be tied together.
- Input and output capacitors need low-impedance grounding. Suggested wide traces with many vias to the ground plane.
- Input/output ceramic capacitors have DC-bias effect. If the output capacitance is too low, it can cause boost to become unstable under certain load conditions. DC bias characteristics should be obtained from the component manufacturer. The DC bias is not considered on component tolerance.