PM8941 Lighting Subsystem

Hardware/Software Document

80-NE399-11 Rev. A

December 13, 2012

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Revision history

Revision	Date	Description
A	December 2012	Initial release

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1 Overview

1.1 Introduction

This document describes the three-string white light emitting diode (WLED) backlight boost driver on PM8941. This document contains the software instructions to:

- Initialize the WLED driver
- Turn it on or off
- Change the brightness settings
- Enable individual brightness control of each string

1.2 Acronyms

Table 1-1 lists terms used in this document.

Table 1-1 Acronym list

Acronym	Description
BOM	Bill of materials
CABC	Content adaptive backlight control
FSW	Switching frequency
LCD	Liquid crystal display
LSB	Least significant bit
MSB	Most significant bit
OVP	Over voltage protection
PBS	Programmable booting and sequencing (OTP and RAM-based implementation of a PMIC-based command sequencer)
PFM	Pulse-frequency modulation
PMIC	Power management IC
PWM	Pulse-width modulation
rms	Root mean square
SPMI	Serial power management interface
VI	Verification/integration
VPH_PWR	Main power supply to PMIC
WLED	White light emitting diode

1.3 Reference documents

Table 1-2 lists reference documents that provide additional information.

Table 1-2 Reference documents

Number	Document	DCN
1	*PM8941 Device Specification*	80-NA555-1
2	*PM8941 Device Revision Guide*	80-NA555-4
3	*PM8841 and PM8941 Design Guidelines*	80-NA555-5
4	*PM8841 and PM8941 Training Slides*	80-NA555-21

1.4 WLED driver high-level overview

The primary goal of this module is to drive a series/parallel combination of strings of WLEDs that are used to backlight LCD panels.

The WLED driver is an inductive boost topology that adaptively boots the battery voltage high enough to support a series connection of WLEDs with regulated current sink headroom; e.g., with eight LEDs in series, the battery voltage is boosted to approximately 24.5 V (assuming 3 V per LED and 0.5 V headroom for the current sink).

Key features include:

- Three current sinks capable of 0 to 25 mA each.
- Each current sink can be independently controlled via a combination of the brightness control register, full-scale current setting register, and an external content adaptive backlight control (CABC) pulse-width modulation (PWM) input.
  - e.g., in Figure 1-1, the full-scale current setting is 25 mA, the brightness register setting is at 50%, and the CABC PWM duty cycle is 80%.
  - The resulting LED current is 25 mA * 0.5 * 0.8 = 10 mA.

NOTE: The analog dimming method is supported.

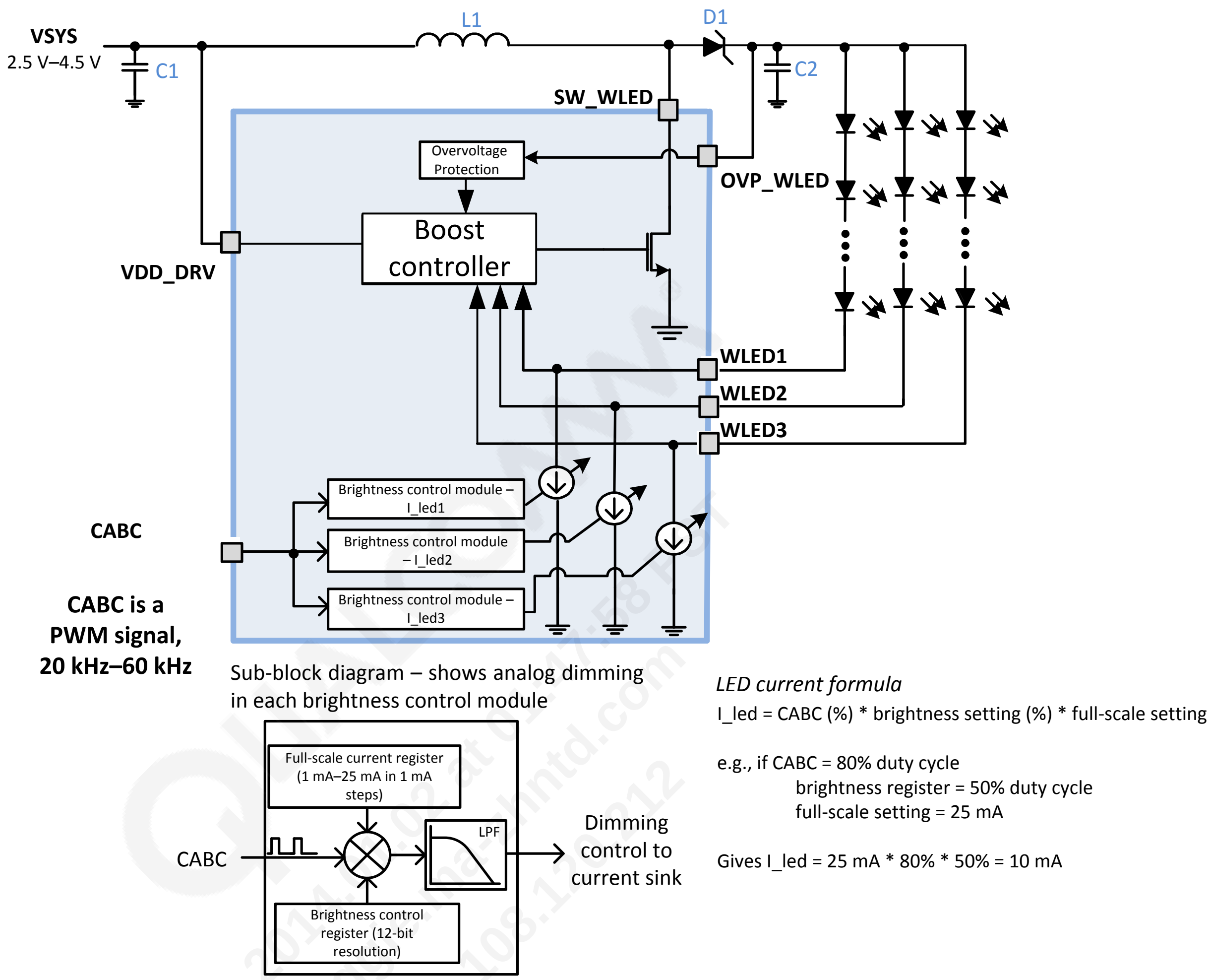

Figure 1-1 WLED high-level block diagram

1.5 Pins

Table 1-3 Pins

#	Pin name	Number of package pins	Type	Noisy	Sensitive	Comments
1	WLED_GND	2	G	Y	N	Dedicated power ground for switching the NFET and driver
2	WLED_IGND	1	G	N	Y	Dedicated low-current analog ground
3	WLED1	1	A	N	Y	LED sink 1
4	WLED2	1	A	N	Y	LED sink 2
5	WLED3	1	A	N	Y	LED sink 3
6	SW_WLED	2	P	Y	N	Boost switch node
7	VDD_WLED	1	P	Y	N	Supply pin for gate driver
8	OVP_WLED	1	A	Y	N	Output voltage, also over voltage protection (OVP) sense
9	CABC	1	D	Y	N	Content adaptive backlight signal

Note: For type, G = ground, P = power, A = analog, and D = digital.

1.6 Support

For debugging support on the WLED, provide the following:

- A schematic showing the WLED pin connections in the application circuit
- The LED configuration, or if a LCD panel is used, the LCD panel datasheet showing the maximum LED voltage across panel
- The SBI register settings
- The CABC settings, if used
- If possible, also include:
  - The voltage on the WLED_DRV pins
  - The voltage on VREG_WLED pin
  - The current into WLED_DRV
  - The input current when the backlight is enabled
  - The voltage waveform at the SW_WLED node

1.7 PMIC support

Table 1-4 PMIC and number of strings

PMIC	Number of strings
PM8941	3

1.8 Frequently asked questions (FAQs)

1.8.1 How do customers program the output voltage if they do not see a register?

You cannot program the output voltage. The WLED adaptively adjusts the voltage based on the number of LEDs and the voltage per LED.

1.8.2 What are customers programming?

LEDs are controlled by current, not by voltage.

Programming for the WLED driver, other than initialization, is to control the current in the LED string that flows into the WLED_DRV pin.

1.8.3 Where is the feedback/sense node? Is it VREG_WLED?

The WLED_DRV pin also serves as the feedback node. The WLED closed loop control regulates this pin to 500 mV (default setting).

VREG_WLED senses the output voltage and stops the WLED driver boosting if it crosses the OVP threshold.

1.8.4 Why is the VREG_WLED pin necessary?

Consider the following scenarios:

- The phone is used in cold conditions. The LED voltage is 3.6 V/LED, and there are 10 LEDs in a string.
- One or more LEDs in the LCD panel explodes, and there is no load on the output.
- The output capacitor self-destructs or is too small in value.
- A panel that requires a higher voltage than the internal limits allow is used.

In each case, the headroom (500 mV) requirement will not be met, and the boost will adaptively increase the output. However, if the output voltage increases without being checked, it may cause electrical stress on the WLED device and components.

VREG_WLED is used as a fault protection feature.

1.8.5 The output voltage is 35 V on the output voltage, but the specification is for 33 V maximum to ground.

The over voltage protection (OVP) threshold, where 35 V is the default setting, is being reached. See Section 1.28.

1.8.6 What is the maximum voltage that can be supported?

The maximum voltage is 33 V, which includes the headroom voltage in the device specification.

The output voltage is approximately 25.5 V. Functionality checks have verified support for up to 10 LEDs (approximately 32 V) on the bench. The maximum voltage specification is currently being evaluated over process and temperature for a number of strings in use. See Section 1.12.

1.8.7 What if a string is enabled and there are no LEDs on that string?

This can cause problems. When a string is enabled in the register, it enables the biases to the current sink and puts a voltage on the reference (+ve) terminal of the current sink OTA (see Figure 1-2). It will try to pull current; however, when the sting is not connected or grounded, there is no current flow and the WLED_DRV pin voltage collapses.

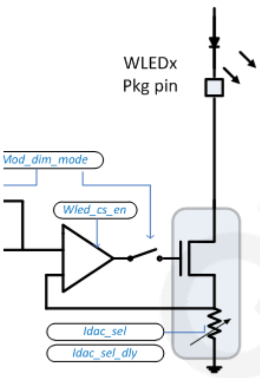

Figure 1-2 WLED_DRV pin collapse

This causes a nondeterministic behavior and will likely result in the output reaching the OVP threshold.

As a general guideline, do not enable a string that is either not connected or grounded.

1.8.8 Is VREG_WLED the output/input to the WLED driver?

It is neither. Current consumption in that pin is 2 mA rms; the pin name and function do not match.

1.8.9 The customer LED configuration does not match the QTI WLED-supported configuration.

Customers have LCD panels with varying LED configurations. It is difficult to meet every requirement.

- Most current generation touchscreen phones are one string, with eight to ten LEDs per string.
- Next generation touchscreen phones are likely to be two strings, with six to eight LEDs per string.
- Tablets typically require four to eight strings and cannot be supported with the QTI driver.

1.8.10 What does 8s1p mean?

This indicates eight LEDs in series (s) and one in parallel (p), i.e., one string.

1.8.11 How many LEDs can be supported?

This is a common question. Customers may want to stack up as many LEDs as possible in a single string. There are two problems:

1. LEDs are almost never binned for their forward voltage.
   a. Expect about ±100 mV of variation in a single bin from the same vendor.
   b. Expect an even wider variation between vendors.

   This means that if vendor A and B both have panels with 10 LEDs in them, but vendor A's LEDs are 3.3 V at 20 mA and vendor B's LEDs are 2.9 V at 20 mA, then panel A is outside the supported range, but panel B can be supported.
2. The LED forward voltage changes with temperature and increases inversely proportional to the temperature. Now, panel B that is 2.9 V, at 20 mA per LED, at room temperature will go over voltage.

NOTE: Information from the LCD panel vendor about the maximum voltage across the panel, at a given current and temperature is required (most vendors will provide the maximum voltage per LED; however, the LED forward voltage distribution is also required).

1.8.12 Why is the number of LEDs still used to create the module specification?

Competition ensures that LED forward voltage used for backlighting is approximately 3.0 V–3.1 V, per LED, at 20 mA at room temperature.

It is also an easy to describe, first-order way to differentiate between products.

1.8.13 What is the correct way to create the module specification for LED support?

Provide the supported panel voltage for the number of strings in use. See Section 1.12 for the supported operating area.

1.8.14 What are some common LED configurations and voltages seen for current and next generation phones?

See Section 1.11.

1.8.15 Can 10 LEDs be supported in one string and two LEDs supported in the other?

While unbalanced string support is the goal, this is currently under evaluation. Use balanced strings.

1.8.16 What is the Rz, Cz slope compensation?

Settings are needed to enable the WLED to have stable output behavior under all conditions to support a wide component range from 4.7 µH–10 µH inductors and 2.2 µF–10 µF output capacitors.

Setting the correct compensation settings is important; otherwise, this results in unstable boost output behavior.

NOTE: **APIs or register information on the WLED compensation settings will be provided.**

1.8.17 What BOM has QTI used for its WLED characterization?

The same BOM has been used for one, two, and three strings. Optimization for cost and package size versus string support and efficiency is possible and is ongoing since inductor parameters are constantly improving.

1.8.18 Efficiency is not as good as what QTI is reporting.

See the Section 1.28.

1.8.19 Which PWM source should be used?

Use the 12-bit modulator by default.

LPG connections are also provided but are used only for auto pattern generation.

1.8.20 Customers need 100, 256, and 512 dimming steps.

Map the dimming steps to the 12-bit dimming code.

1.8.21 What register setting should be changed for dimming?

Keep the full-scale setting (IDAC_SEL) fixed. Change only the 12-bit dimming code.

1.8.22 What is content adaptive backlight control (CABC)? What are the specifications?

See Section 1.10.1.

1.8.23 Can I connect my ambient light sensor to the WLED driver?

See Section 1.10.2.

1.8.24 My dim codes are not being updated.

See Section 1.28.

1.9 WLED interface to other modules in core

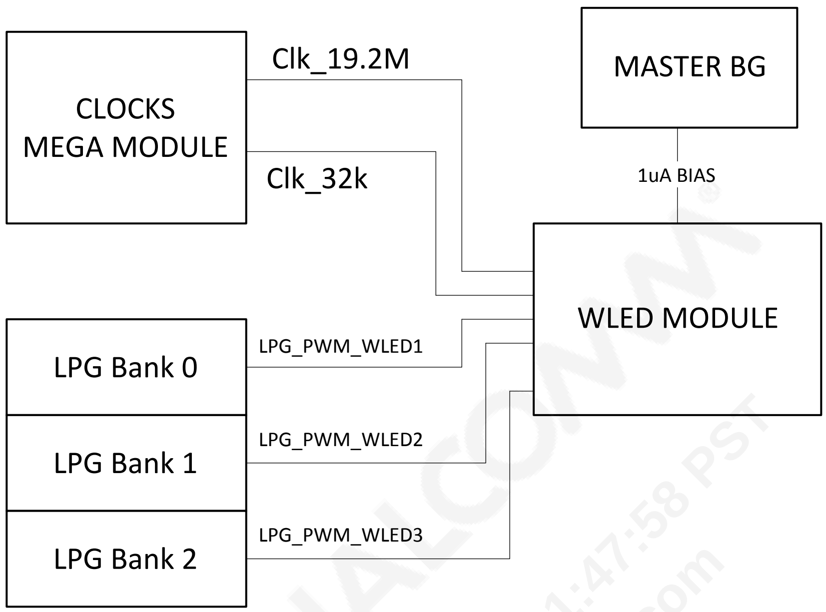

Figure 1-3 WLED interface to other modules

WLED module interfaces with:

- Clocks mega module – For 19.2 MHz and 32 kHz clocks. 19.2 MHz is used for the internal modulator.
- LPG – Three banks provide a 6/9-bit PWM signal with pattern generation capability.

By default, QTI does not intend to use the LPG PWM signals.

- Master bandgap – provides a 1 µA bias current

When the PMIC is powered up:

- The master bandgap is on
- The clock mega module is on, and clock is requested by WLED module when the WLED modulator is enabled

NOTE: Other than configuring the WLED registers, no other module needs to written to enable WLED functionality.

1.10 WLED driver interface in the system

1.10.1 CABC

CABC has improved the run-time system efficiency of the LCD lighting system. It is based on the premise that perceived brightness of an image can be controlled by a modulation of the pixel brightness and the backlight brightness.

A dark image appears dark because the pixels in the LCD filter do not allow much light to shine through. However, the same effect can be achieved by using a dimmer backlight and controlling the pixel layer to allow more light to shine through. In other words, the backlight is dimmed and the image is boosted, resulting in the same perceived brightness. Typically, some kind of histogram analysis is done on the image to determine the maximum brightness than needs to be displayed.

- This histogram analysis is done either in a display driver IC onboard the LCD panel or in the MSM™ device. The end result is brightness control information that is typically sent out as a PWM signal by the MSM device or the display driver IC.
- SPMI writes from the MSM device to the 12-bit dimming register.

1.10.2 Ambient light sense interface

Almost all phones have an ambient light sense (ALS) interface to modulate the WLED brightness. Output from ALS can be used to control keypad lighting or used to modulate the screen display. ALS output can be an analog signal or a PWM.

An example of CABC using MSM software control and ALS using CABC is in Figure 1-4.

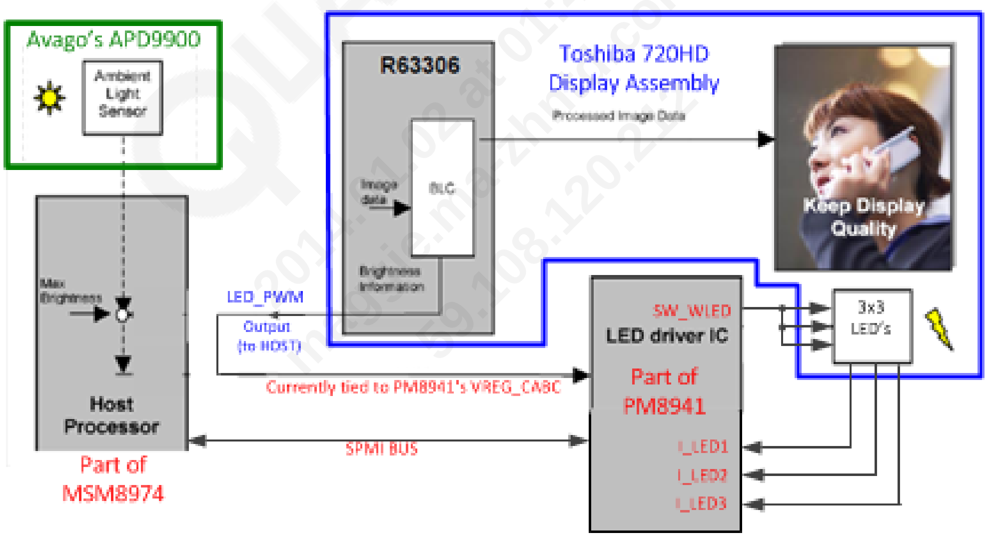

Figure 1-4 CABC example used in MSM8974

In the Figure 1-4 example, the panel is driving the CABC pin. Alternatively, the CABC pin could be driven by the MSM device.

1.11 Platform and panel-specific information

Table 1-5 Platform-specific information

PMIC	LCD vendor	LED configuration	Typical voltage across this panel	Maximum voltage across this panel	Typical full-scale current in each string
PM8038 – Fluid	Sharp 4.3”	10s1p	30 V	33 V	20 mA
PM8941 – Fluid	Toshiba 4.3”	3s3p	~ 10 V		25 mA
PM8941 – MTP	TBD	TBD	TBD	TBD	TBD

1.12 Supported operating area

Settings include:

- FSW = 1.6 MHz; the same BOM is used for all string configurations.
- The characterization includes actual LEDs.

Table 1-6 Settings

LED string configuration	Current per string (mA)	Input voltage range (V)	Output voltage (V)	Characterization
8s1p	0–25	3–4.2	~ 25	Over PVT
8s2p	0–25	3–4.2	~ 25	Over PVT
8s3p	0–25	3.6–4.2	~ 25	Mostly at 3.6 V for current accuracy
9s1p	0–25	3–4.2	~ 28	Done for efficiency comparison, mostly at 3.6 V
10s1p	0–25	3–4.2	~ 28	Done for efficiency comparison, mostly at 3.6 V
9s2p	0–25	3–4.2	~ 28	Over temperature
10s2p	0–25	3–4.2	~ 31	Singe device characterization showed operation down to 3 V
7s3p	0–25		~ 22	TBD

1.13 Dimming method

The module supports analog dimming; in this dimming method, **the LED current is continuous** and linear through brightness changes.

1.14 Dimming support

- The dimming module supports analog dimming.
- The dimming module implements its own modulator.
- There are two resolution modes available with this internal modulator: 9-bit and 12-bit.
- Either resolution mode can be used for analog dimming.
- The dimming module is self-sufficient; however, to support pattern generation, it also accepts an input from the LPG module.
- The dimming module also accepts an input from CABC.
- The CABC signal acts as a global modulating signal for only the internal modulator. CABC will have no effect if the LPG module PWM output is selected as the modulation signal.
- The current sink is implemented as a current DAC with segments of 1 mA each, up to 25 mA. This sets the full-scale value for the current sink.
- Dimming is then done off the full-scale value setting.
- Each current sink is independently controlled for resolution mode, CABC modulation enable or disable, brightness setting, and current DAC setting
- Average LED current = brightness register value/2^{RES} * full-scale current * CABC duty cycle, where RES is the modulator resolution.

The default use case for dimming: Analog dimming + 12-bit resolution + CABC.

- For analog dimming**, it is recommended that the modulating signal frequency before the low pass filter be greater than 20 kHz**. Any ripple on the low pass filter output also appears on the current sink reference.
- When CABC is a test input**, it is recommended to use a 20 kHz or higher signal.**

In summary:

- Analog dimming – Use 12 bits of dimming and use a 1.2 MHz modulator clock (1.2 MHz is the default but higher frequencies are also acceptable at an increased cost of power dissipation) and CABC PWM frequency > 20 kHz and < 40 kHz.

The default setup in the WLED driver is for analog dimming.

- The allowable PWM frequency range in Table 1-7 assumes using 19.2 MHz as the modulator clock.
- The LPG 6-bit mode is shown for completeness; however, it is unlikely that 6 bits of resolution will be used for LCD backlight during mission mode.

Table 1-7 data is shown for completeness**.** Yellow shading indicates the most common usage.

Table 1-7 Dimming support matrix for WLED driver with the allowable PWM frequency range and recommended values

Dimming method	Modulator	Resolution	PWM frequency min	PWM frequency max	Recommended PWM frequency	CABC modulation	Auto pattern generation support
Analog	WLED init	9-bit	37.5 kHz	37.5 kHz	37.5 kHz	Y	N
		12-bit	38.4 kHz	~ 19.2 MHz	Varies	Y	N
	LPG	9-bit	18.75 kHz	37.5 kHz	37.5 kHz	N	Y
		6-bit	25 kHz	300 kHz	100 kHz	N	Y

1.14.1 Using the LPG PWM signal

- This is used in the module to support the LCD panel fading.
- It should be possible to fade in the brightness of the display using the LPG PWM and then switch over to the internal modulator to support CABC, if needed
- Fading can also be done by software control. The LPG module frees up the software from this task (a typical smooth fade can require up to 40 brightness changes). These brightness steps are stored in the LUT associated with the LPG.

1.15 CABC control

- CABC can be individually configured for each string.
- Table 1-8 lists the CABC specifications. **If CABC is not being driven externally, it should be pulled down to ground and not left floating.**

Table 1-8 CABC specifications

Parameter	Condition	Min	Typ	Max	Units
CABC PWM frequency	Analog dimming	20		60	kHz
CABC duty cycle		0		100	%
Input level low voltage			0		V
Input level high voltage			1.8		V

1.16 OVP

Consider the following two scenarios:

1. The LED forward voltage is 4 V at 10 mA, and there are nine LEDs in a stack for a single string.
2. During operation, one LED fails and behaves as an open circuit.

Feedback for the WLED driver is the headroom across the current sinks. Hence, in both scenarios, the boost regulator attempts to increase the output voltage. Other than being limited by the duty cycle (see Section 1.17), the output voltage can increase to a high enough value to potentially damage the switch or the inductor

Once OVP is triggered,

- The boost will stop switching and discharge the inductor energy.
- Wait for the output to drop by 2 V from the OVP trigger point, before switching again.

OVP is a common feature for WLED backlight driver circuits.

1.17 Duty cycle limitations

The boost regulator will not achieve 100% duty cycle. (a) This is not a valid steady state behavior, since a 100% duty cycle does not apply in theory, and (b) during dynamic operation 100% duty cycle is avoided since it can result in large electrical stresses on the inductor and switch. For the WLED driver, the maximum duty cycle is a function of the switching frequency and is expressed here:

bst_max_duty<1:0>

Maximum duty cycle control for boost.

0d: (1/FSW – 26 ns) * FSW

1d: (1/FSW – 52 ns) * FSW

2d: (1/FSW – 104 ns) * FSW

3d: (1/FSW – 156 ns) * FSW

1.18 Reducing current during high-current GSM PA turn on

When the GSM PA turns on, the full power transmit draws 2 A+ from the battery. To minimize the concurrent current draw, a WLED driver setting reduces the output current by half when a high power transmit occurs

This feature can be enabled/disabled in the software.

Table 1-9 PMICs and WLED current reduction

PMIC	WLED current reduction internal connection
PM8941	TX_GTR_THRES (GPIO)

1.19 Software control of the WLED driver

Basic functionality consists of three primary functions:

1. Turning on the panel by enabling the boost regulator and current sinks
2. Turning off the panel by disabling the boost regulator and current sinks
3. Dimming the LCD panel using one or more current sink control

Advanced software functionality consists of:

1. Dimming/disabling only one string in a multistring design
2. Moving from a LPG-based fading pattern to a steady state analog dimming and vice-versa
3. Controlling the step size of the brightness change and dividing a large step size into a sequence of smaller steps

NOTE: This avoids large voltage drops at the battery due to large load steps.

4. Mapping compensation settings for given battery voltage and output current levels
5. Synchronizing updates to IDAC_SEL with updates to the 12-bit dimming code

1.19.1 Register control of the WLED driver – boost loop overview

Typically, most of the boost settings – except for the global module enable/disable bit, wled_en_reg – are not updated after initialization.

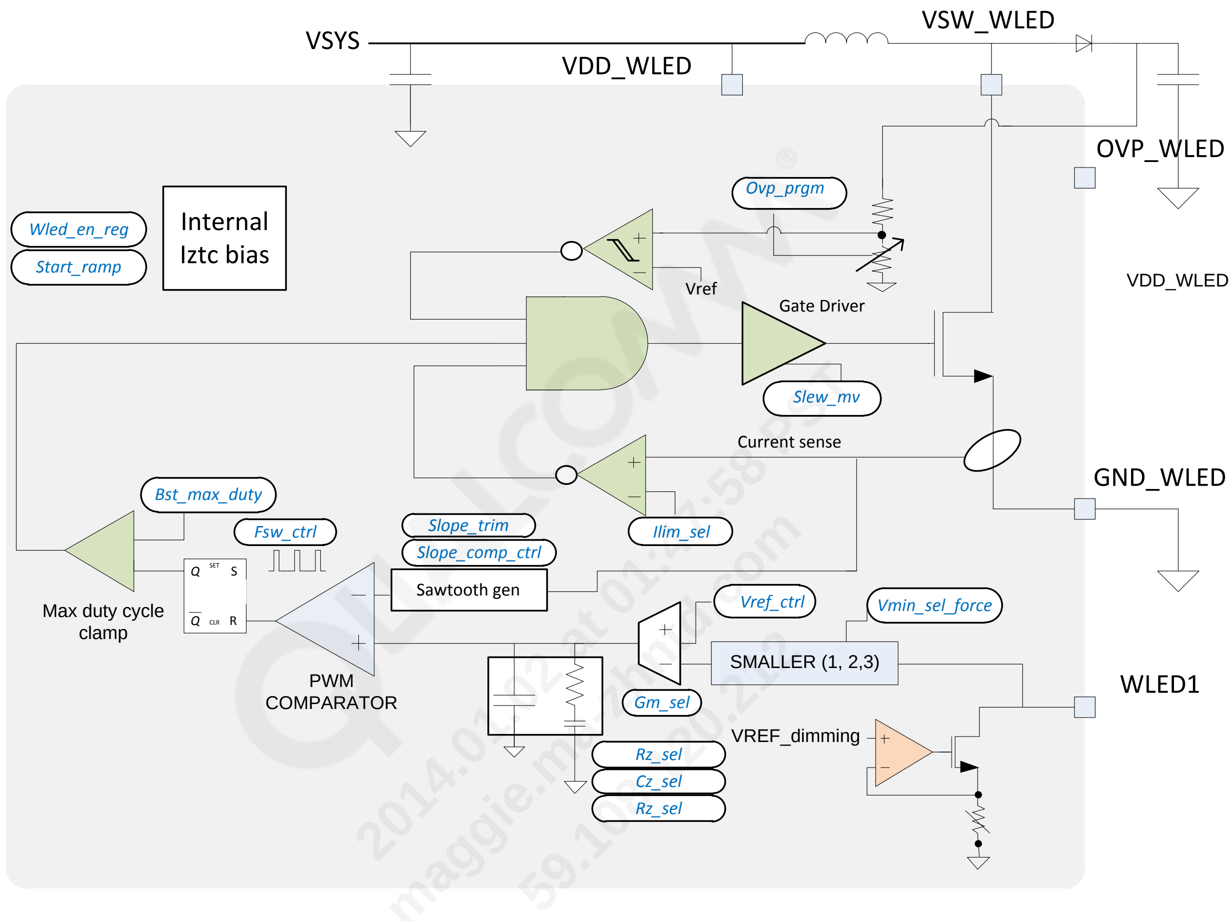

Figure 1-5 Register control of the WLED driver – boost loop overview

1.19.2 Register control of the WLED driver – dimming overview

These registers are likely to be repeatedly updated in the software.

Table 1-10 Register control of the WLED driver – dimming overview

Bit field	Function
Cabc_en	Enables CABC for the particular string
Wled_mod_en	Enables the modulator for dimming control. Keep this enabled until the current sink/module is turned off.
Wled_cs_en	Enables the current sink biases and analog. Keep this enabled until the current sink/module is turned off.
Mod_pwm_mode	Selects between 12-bit (default) and 9-bit (default)
Mod_clk_cntrl	Selects the modulator clock. Keep the default for analog dimming.
Idac_sel	Full-scale current. The default operation is to keep this fixed. Advanced functionality can use a simultaneous update to the 12-bit code and full-scale code.
Idac_sel_dly	Delays the update to the full-scale current and attempts to match the path delays from the 12-bit modulator (via low-pass filter) to the current sink.
Ext_pwm_en	Selects between the internal or LPG modulator
Led_duty_cycle	9 or 12-bit dimming code
Led_sync	Needs to toggle from 0 to 1 to update the full-scale current or dimming code

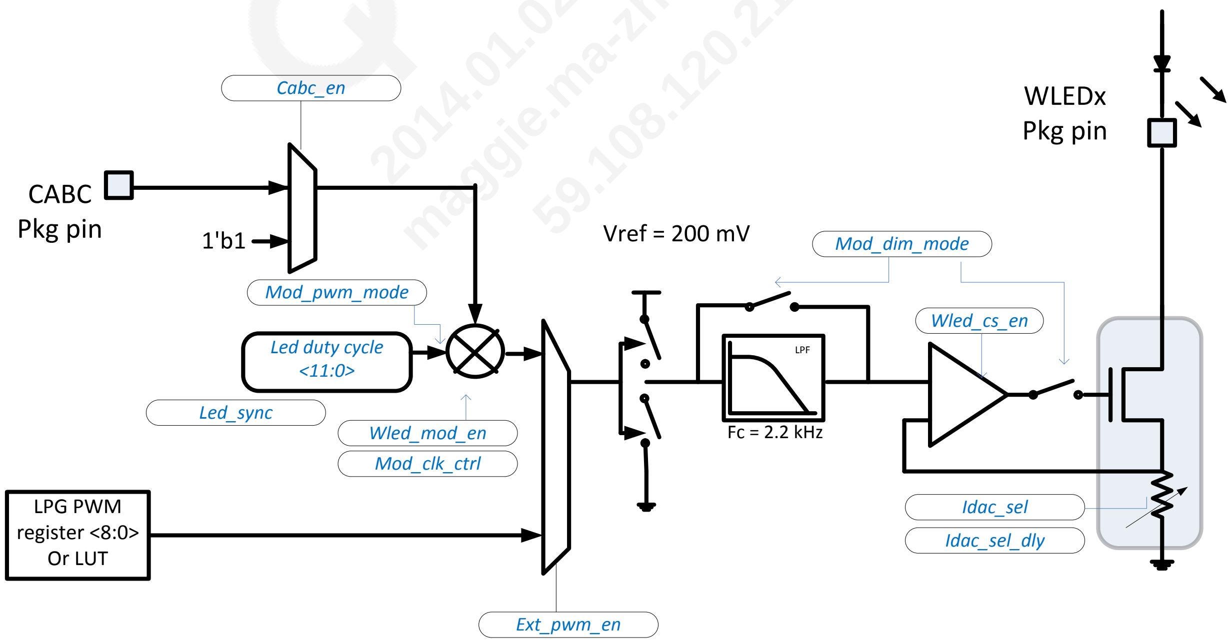

Figure 1-6 Register control of the WLED driver – dimming overview

1.20 Number of peripherals and addressing

WLED is a single peripheral. The base address is 0xD800.

1.21 Turning on the LCD panel – SPMI writes for initialization and three-string activation (Toshiba Fluid panel), three LEDs in each string

- Boost regulator and current sinks are enabled together at the end of this routine.
- The current sink is set to a maximum of 25 mA (default).
- The register sequence below initializes the boost and current sink and then enables the boost module.
- A large number of settings are default settings that are shown for completeness.

Table 1-11 Default settings that are not expected to change (i.e., init)

Step #	Address	Register	Value	Notes
1	0xD848	FEEDBACK_CTRL	0x00	Auto selection of feedback between the three strings
2	0xD849	VREF_CTRL	0x02	Headroom selection = 500 mV
3	0xD84A	MODULATION	0x0C	1.2 MHz modulator clock 12-bit resolution Analog dimming
4	0xD850	SLOPE_CMP_CAP	0x07	At default
5	0xD851	SLOPE_CMP_ADJ	0x00	At default for given BOM
6	0xD852	BIAS_GEN_DELAY	0x01	At default
7	0xD853	SOFTSTART_DELAY	0x02	At default
8	0xD854	SLEW_RATE_CTRL	0x02	At default
9	0xD855	VLOOP_CMP_RES	0x03	At default
10	0xD856	VLOOP_CMP_GM	0x0F	At default
16	0xD857	VLOOP_CMP_CAP	0x03	At default
17	0xD858	VLOOP_CMP_HCAP	0x00	At default
18	0xD859	EN_HW_BL_REDN	0x00	At default (see Section 1.18)
19	0xD84D	WLED_OVP	0x00	

Table 1-12 Non-default settings that are not expected to change (i.e., init)

Step #	Address	Register	Value	Notes
1	0xD84B	MAX_DUTY_CYCLE	0x02	The default is 0x00.
2	0xD84C	SWITCHING_FREQ	0x00	1.6 MHz is currently the default setting; however, QTI is currently evaluating 800 KHz and 960 KHz for better efficiency and will update this document once validation is complete.
3	0xD84E	WLED_ILIM	0x03	805 mA current limit setting for switching frequency of 0.8 MHz (see Section 1.23)

Table 1-13 Normal operation registers

Step #	Address	Register	Value	Notes
20	0xD861	LED1_IDAC_DLY	0x02	Default
21	0xD862	LED1_FULL_SCALE	0x19	25 mA (default)
22	0xD863	LED1_MOD_SRC	0x00	Default = internal modulator
23	0xD866	LED1_CABC_EN	0x00	Enable as per usage
24	0xD870	LED2_MOD_EN	0x80	Enable modulator
25	0xD861	LED2_IDAC_DLY	0x02	Typically at default setting of 25 mA
26	0xD862	LED2_FULL_SCALE	0x19	25 mA (default)
27	0xD863	LED2_MOD_SRC	0x00	Default = internal modulator
28	0xD866	LED2_CABC_EN	0x00	Enable as per usage
29	0xD880	LED3_MOD_EN	0x80	Enable modulator
30	0xD881	LED3_IDAC_DLY	0x02	Typically at default setting of 25 mA
31	0xD882	LED3_FULL_SCALE	0x19	25 mA (default)
32	0xD883	LED3_MOD_SRC	0x00	Default = internal modulator
33	0xD886	LED3_CABC_EN	0x00	Enable as per usage
34	0xD840	LED1_BRIGHT_LSB	0xFF	Default
35	0xD841	LED1_BRIGHT_MSB	0x0F	
36	0xD842	LED2_BRIGHT_LSB	0xFF	Default
37	0xD843	LED2_BRIGHT_MSB	0x0F	
38	0xD844	LED3_BRIGHT_LSB	0xFF	Default
39	0xD845	LED3_BRIGHT_MSB	0x0F	

Table 1-14 Enabling the WLED driver

Step #	Address	Register	Value	Notes
1	0xD84F	EN_CURRENT_SINK	0xTBD	Enables one, two, or three strings Note: For the Fluid panel (Toshiba 3s3p), the setting is 0xE0.
2	0xD846	MODULE_EN	0x80	Enables the entire module

Table 1-15 Disabling the WLED driver – lowest power state setting

Step #	Address	Register	Value	Notes
1	0xD846	MODULE_EN	0x00	Disables the entire module, including boost and current sink operation

In the Table 1-16 example, the brightness register for LED1 is changed twice: first to 40%, then to 33%.

NOTE: In general, the software should change the brightness of all three strings to the same value.

Table 1-16 Changing the brightness levels of the LCD panel

Step #	Address	Register	Value	Notes
1	0xD840	LED1_BRIGHT_LSB	0x66	
2	0xD841	LED1_BRIGHT_MSB	0x06	40% duty cycle
3	0xD847	ILED_SYNC	0x00	Need to clear the go or sync bit
4	0xD847	ILED_SYNC	0x01	Go bit that writes this value to the modulator

1.22 Compensation settings

The WLED driver is a closed loop system since it senses the feedback voltage on the WLED return pin and adjusts the output voltage as needed. A closed loop system needs to be stable and respond in a controlled manner under the effect of all load steps. Compensation settings allow the loop response to be stable under the load step conditions.

Table 1-17 is used as a guideline. The configuration with a 10 µH/4.7 µF capacitor (nominal values) has been characterized thoroughly.

NOTE: **Recommendations are subject to change.**

Table 1-17 Compensation settings

String configuration	FSW (MHz)	L (µH, nominal), L (µH, derated, worst case)	C (µF, nominal), C (µF, derated)	Rz (code) WLED_CNTRL_15 bits 7:4	Cz (code) WLED_CNTRL_16 bits 3:2	Gm (code) WLED_CNTRL_15 bits 3:0	Slope comp (code) WLED_CNTRL_11 bits 7:6	Slope trim (code) WLED_TRIM_4 bits 7:5	Cp (code) WLED_CNTRL_16 bits 1:0
8s1p–10s1p	0.8–1.6	10	4.7	0011	11	1111	00	111	00
8s2p	0.8–1.6	10	4.7	0011	11	1111	00	111	00
8s3p	0.8–1.6	4.7	4.7	0111	11	1111	11	111	00
8s1p	1.6	10	2.2	0001	11	1111	00	111	00

1.23 Current limit settings

Assumes FSW = 1.6 MHz

For FSW = 0.8 MHz, increase the current limit settings by one code

Table 1-18 Current limit settings

Number of strings	Max number of LEDs per string	Current limit setting
1	8–9	525 mA (010, this is the default)
1	10	805 mA
2	8	980 mA (100)
3	8	1260 mA (101)

1.24 Turning off the LCD panel – SBI writes

- Boost is turned off. NFET will stop switching.
- The modulator is automatically disabled.
- The current sink bias is automatically disabled.
- Programming the 12-bit programming code or the full-scale setting register (WLED_CTRL_2/3/4) is not required.
- Rock bottom sleep current – When the LCD panel is disabled, **the boost must be disabled.** Disabling the current sinks is not sufficient to turn off the module.

  This is currently done with a single SBI write.

Table 1-19 Turning off the LCD panel – SBI writes

Step #	Address	Register	Value	Notes
1	0xD846	MODULE_EN	0x00	Bit 7 is a master enable/disable bit and will disable everything

1.25 Turning off/on one string in a multistring application

- Boost is enabled.
- More than one string is used in the application.
- The user wants to turn off one string only.
- Program the sting to a full-scale value of 0x00 and disable the string. This is a robust way to turn the string off.

  However, this requires the full-scale value to be tracked/stored by the software so that it can be restored when the string is turned back on; e.g., string two is to be turned off, and string one is enabled.

Table 1-20 Turning off/on one string in a multistring application

Step #	Address	Register	Value	Notes
1	0xD872	LED2_FULL_SCALE	0x00	Set the full-scale value of string two to 00000. For this example, use 0x14. The software needs to store this setting somewhere for restoring this full-scale value when the string is enabled – or require the customer to input it when the string is enabled.
2	0xD870	LED2_MOD_EN	0x00	Disable the modulator
3	0xD84F	EN_CURRENT_SNK	X0X00000	Disable string two by setting the bit to 0

1.26 Using the LPG to control an external WLED driver

This case example uses MSM8974. GPIO36 controls the backlight IC.

Table 1-21 Initialization part A – Configuring LPG channel 8

Step #	Address	Register	Value	Notes
1	0x1B841	LPG_PWM_SIZE_CLK	0x33	9-bit resolution 19.2 MHz clock select
2	0x1B842	LPG_PWM_FREQ	0x01	18.75 kHz PWM

Table 1-22 Initialization part B – Configuring GPIO36

Step #	Address	Register	Value	Notes
1	0xE340	MODE_CTL	0x16	Digital output SF2
2	0xE341	DIG_VIN_CTL	0x02	1.8 V output
3	0xE342	DIG_PULL_CTL	0x03	
4	0xE345	DIG_OUT_CTL	0x03	CMOS high strength
5	0xE346	EN_CTL	0x80	Enable GPIO36

Table 1-23 Enable LPG8 and run-time brightness changes

Step #	Address	Register	Value	Notes
1	0x1B844	PWM_VALUE_MSB	0x01	When changing the most significant bit (MSB), always write to the least significant (LSB) register.
2	0x1B845	PWM_VALUE_LSB	0xFF	99.97% duty cycle
3	0x1B846	EN_CLTR	0xE4	Enable LPG

Note: Run-time brightness changes are made by writing a new PWM value.

1.27 Interrupts

1.27.1 OVP

- Condition – This interrupt is generated when the output voltage of the boost rail exceeds a programmable threshold voltage (minimum 27 V and maximum. 35 V). This interrupt is active until the output drops by 2 V from the threshold voltage.
- Type – Positive
- Response – An OVP event when a programmed current is entered is a fault. If the design uses more than one string, OVP occurs when all LED strings are an open fault or the software incorrectly enables a string that is not populated. The software can diagnose the OVP fault by enabling one string at a time for multistring usage.

1.27.2 Current limit

- Condition – This interrupt is generated when the inductor current exceeds a programmable threshold (minimum 105 mA and maximum 1.68 A). This interrupt is based on a cycle-by-cycle current limit detection.
- Type – Positive
- Response – A current limit will occurs if the programmed settings are lower than the expected inductor current’s given input voltage, output voltage, and maximum load current settings. A current limit condition during normal operation and over all LED brightness levels is a fault with the WLED module or external components.

1.28 Troubleshooting

Table 1-24 Issues and troubleshooting information

Issue	Troubleshoot
The WLED output voltage is much lower than the expected voltage.	▪ Measure the voltage on WLED_DRV. Is it 0.5 V or lower (e.g., 0.2 V)? ▪ Check the current limit settings, per Section 1.23. ▪ Check the BOM, per the recommended BOM guidelines. A 10 μH inductor is recommended for supporting most current LED configurations. ▪ Check the Vbat. Vbat < 3 V can result in headroom collapse
The WLED output voltage is higher than expected.	▪ Check the OVP setting. Is the output at OVP? ▪ Check the output voltage waveform. Is this sawtooth shaped, with a Vpp of 2 V? If so, this OVP action is confirmed.
The CABC is not working as expected.	Check the CABC specifications, per Section 1.15
The switch node is unstable.	▪ Check the compensation settings for the switching frequency and BOM used, per Section 1.22. ▪ Check current limit settings, per Section 1.23.
The efficiency is lower than the QTI curves.	▪ Ensure that the output is regulating and providing the expected output current. ▪ Check the difference in the BOM. A higher series resistance (DCR) in the inductor can impact the efficiency.
The efficiency is higher than the QTI curves.	Provide this information to QTI.
No change in brightness is observed.	Ensure the sync bit is toggled (WLED_CNTRL_11).

2 Hardware/Application Guidelines

2.1 Inductor selection

Table 2-1 Inductor selection

Vendor	Part number/inductance	Isat max/typ (A)	Itherm max/typ in (A)	DCR max/typ (mΩ)	Withstand voltage (V)	Recommended LED stack
Toko	DFE252012 10 µH	1.0/1.3	0.7/0.9	460(400)	20	8 (~ 27 V)
Cyntec	PIFE 252012 10 µH	1.1/1.2	1.0/1.08	456/380	50	10 (~ 31 V)

2.2 Efficiency vs. BOM selection

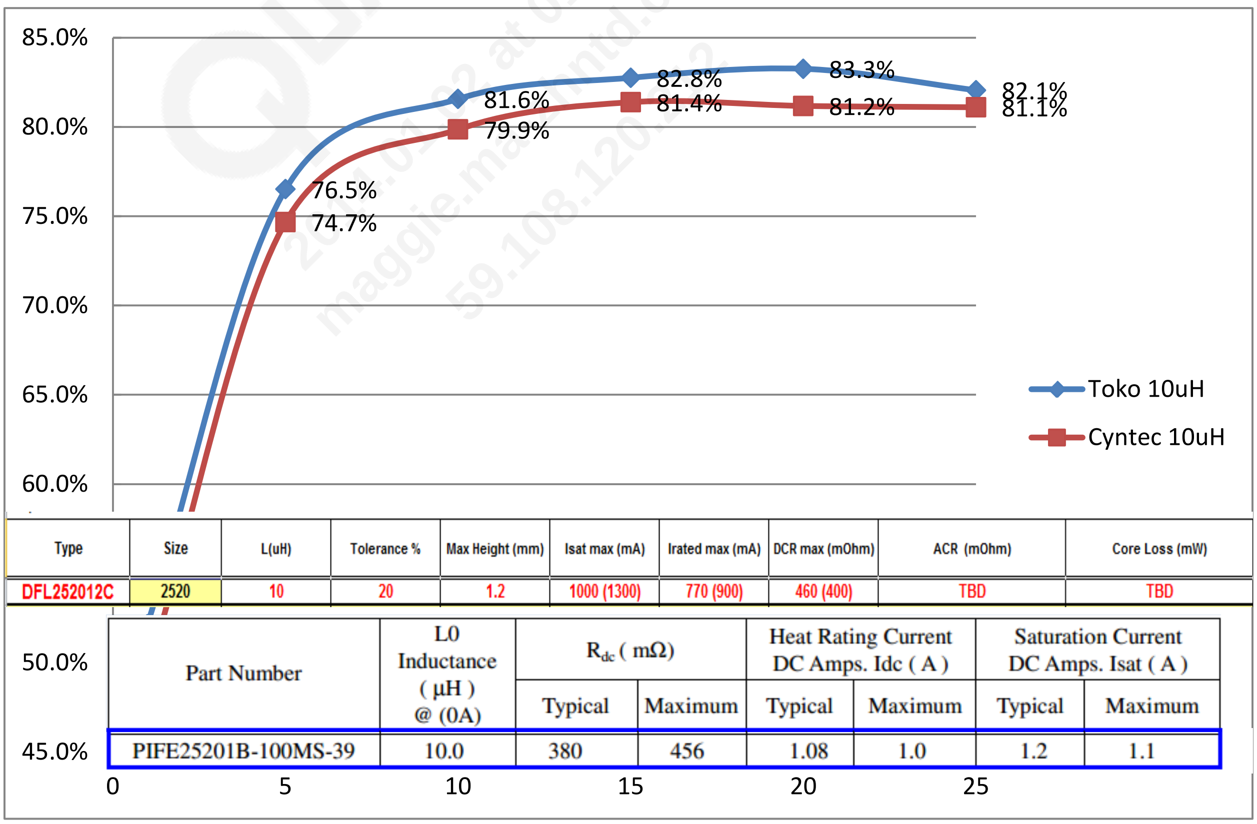

Figure 2-1 Efficiency vs. BOM selection

2.3 Efficiency for 6s2p LED configuration

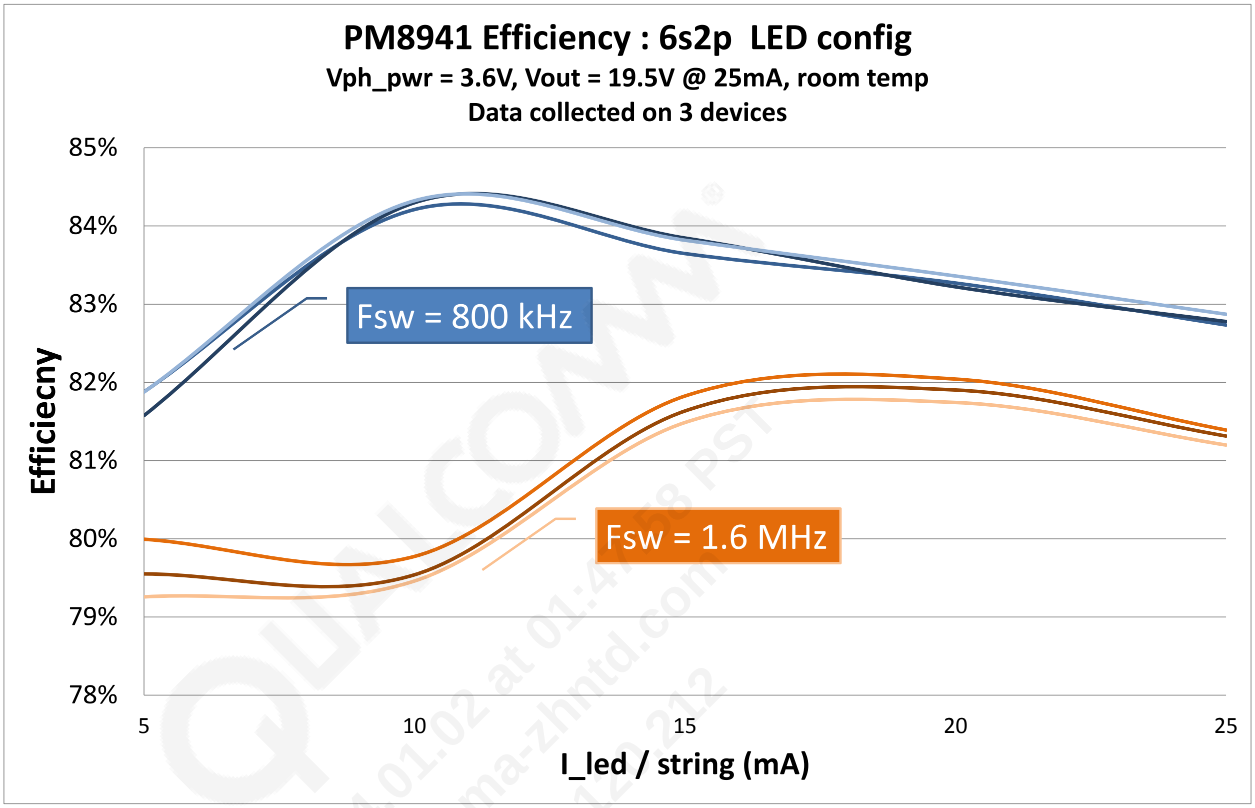

Figure 2-2 Efficiency for 6s2p LED configuration

2.4 Efficiency versus LED configuration

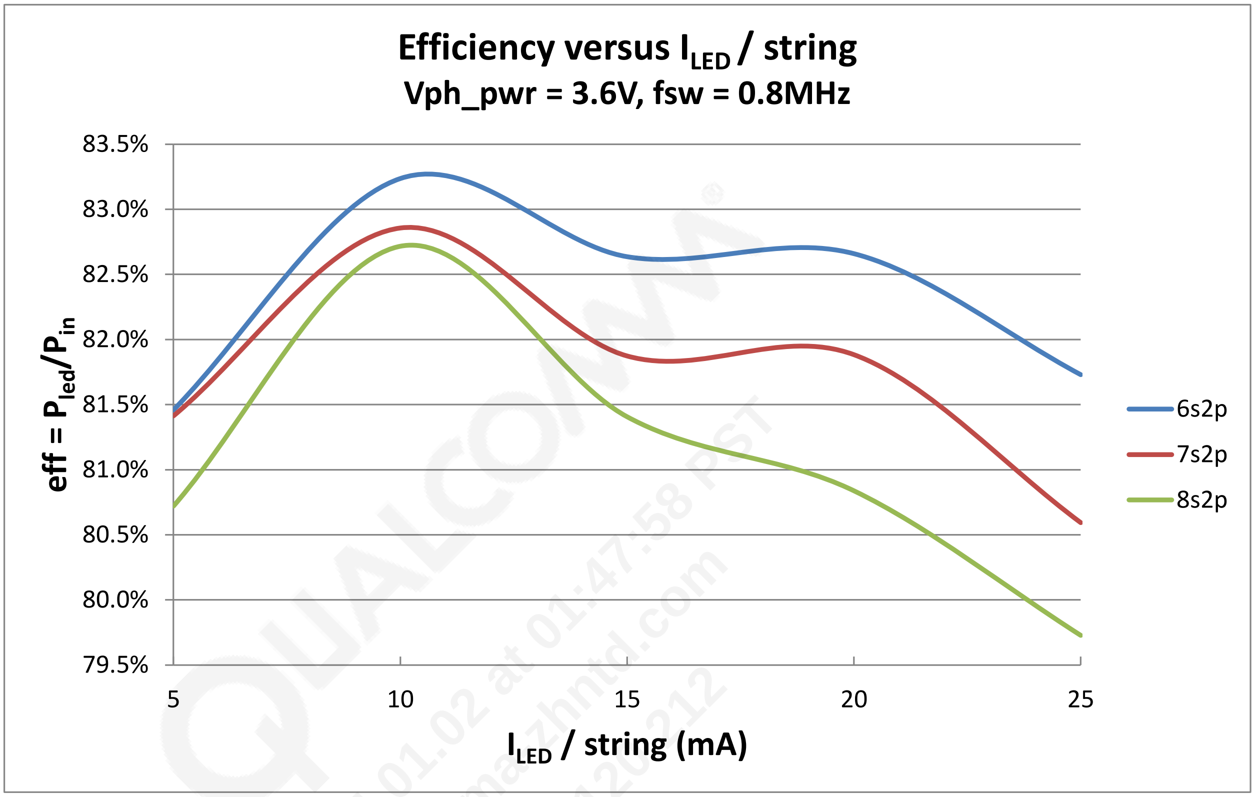

Figure 2-3 Efficiency versus LED configuration

2.5 Layout guidelines

- Trace inductance between the input capacitor to GND_WLED < 10 nH
- Trace inductance between the output capacitor to GND_WLED < 10 nH
- Do not share or route IGND_WLED and GND_WLED with any other ground net on the board. They should directly connect to the ground plane.