LP5811 Synchronous Boost 4-Channel RGBW LED Driver with Autonomous Control

1 Features

- Operating voltage range:
  - Input voltage (V_{IN}) range: 0.5V to 5.5V
  - 1.8V minimum input voltage for start-up
  - Logic pins compatible with 1.8V, 3.3V, and 5V
- High efficiency synchronous boost converter
  - Output voltage (V_{OUT}) range: 3V to 5.5V
  - 140mΩ (HS) / 60mΩ (LS) MOSFETs
  - 1.6A valley switching current limit
  - 95% efficiency at V_{IN} = 4.2V, V_{OUT} = 5.0V, I_{OUT} = 300mA
  - Pass-through mode when VIN > VOUT setting
  - True disconnection between input and output during shutdown
- 4 constant current sinks with high precision:
  - 0.1mA to 51mA per current sink
  - Device-to-device error: max ±5%
  - Channel-to-channel error: max ±5%
  - Ultra-low headroom voltage: 110mV (typ.) at 25.5mA; 210mV (typ.) at 51mA
  - PWM phase shift configurable for each LED
- Ultra-low power consumption:
  - Shutdown: I_{SD} = 0.1μA (typical) when EN = Low
  - Standby: I_{STB} = 26μA (typical) when EN = High and CHIP_EN = 0 (data retained)
  - Active: I_{NOR} = 0.45mA (typical) when LED current = 25.5mA
- Analog dimming (current gain control)
  - Global 1-bit Maximum Current (MC): 25.5mA or 51mA
  - Individual 8-bit Dot Current (DC) setting
- PWM dimming up to audible-noise-free 24kHz
  - Individual 8-bit PWM dimming resolution
  - Linear or exponential dimming curves
- Autonomous animation engine control
- Individual LED dot open/short detection
- Integrated de-ghosting function
- 1MHz (max.) I^2C interface
- –40°C to 85°C operating temperature range

2 Applications

LED animation and indication for:

- Portable and wearable electronics - earbud and charging case, E-cigarette, smart watch
- Gaming and home entertainment - smart speaker, RGB mouse, VR headset, and controller
- Internet-of-Things (IOT) - E-tag, video doorbell
- Networkings - router, access point
- Industrial HMI - EV charger, factory automation

3 Description

The LP5811 is a synchronous boost 4-channel RGBW LED driver with autonomous animation engine control. The device is ideal to support battery-powered applications with 0.5V to 5.5V input voltage range, and it has ultra-low normal operation current with 0.4mA (typical) when illuminate LEDs.

The integrated synchronous boost converter maintains excellent efficiency and keeps the brightness of LEDs stable over a wide operating voltage range. Output voltage can be selected for different LED forward voltage from 3V to 5.5V with 0.1V step. The boost converter can power not only the LEDs driven by the device itself, but also other loads in the system. If the boost converter need to be bypassed, VOUT is used as the power supply input for the LED driver blocks.

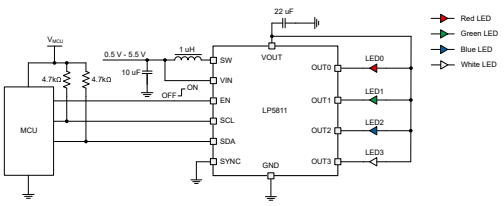
Both analog dimming and PWM dimming methods are adopted to achieve powerful dimming performance. The output current of each LED can be adjusted with 256 steps from 0.1mA to 25.5mA or 0.2mA to 51mA. The 8-bit PWM generator enables smooth and audible-noise-free dimming control for LED brightness.

The autonomous animation engine can significantly reduce the real-time loading of controller. Each LED can be configured through the related registers to realize vivid and fancy lighting effects. The device can generate 6MHz clock signal and use it for synchronizing the lighting effects among multiple devices.

Package Information

PART NUMBER	PACKAGE(1)	BODY SIZE (NOM)
LP5811	DSBGA (12)	1.84mm × 1.43mm
	WSON (12)	3mm × 3mm

(1) Product Preview



Simplified Schematic

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4 Device Comparison

PART NUMBER	Max LED Number	Power Stage	PACKAGE	MATERIAL	I²C Chip Address		SOFTWARE COMPATIBLE
					Bit 4	Bit 3	
LP5813	12	Boost	DSBGA-12	LP5813AYBHR	0	0	Yes
				LP5813BYBHR	0	1	
				LP5813CYBHR	1	0	
				LP5813DYBHR	1	1	
			WSON-12	LP5813ADRRR	0	0	
				LP5813BDRRR	0	1	
				LP5813CDRRR	1	0	
				LP5813DDRRR	1	1	
LP5812	12	Linear	DSBGA-9	LP5812AYBHR	0	0	
				LP5812BYBHR	0	1	
				LP5812CYBHR	1	0	
				LP5812DYBHR	1	1	
			WSON-8	LP5812ADSDR	0	0	
				LP5812BDSDR	0	1	
				LP5812CDSDR	1	0	
				LP5812DDSDR	1	1	
LP5811	4	Boost	DSBGA-12	LP5811AYBHR	0	0	
				LP5811BYBHR	0	1	
				LP5811CYBHR	1	0	
				LP5811DYBHR	1	1	
			WSON-12	LP5811ADRRR	0	0	
				LP5811BDRRR	0	1	
				LP5811CDRRR	1	0	
				LP5811DDRRR	1	1	
LP5810	4	Linear	DSBGA-9	LP5810AYBHR	0	0	
				LP5810BYBHR	0	1	
				LP5810CYBHR	1	0	
				LP5810DYBHR	1	1	
			WSON-8	LP5810ADSDR	0	0	
				LP5810BDSDR	0	1	
				LP5810CDSDR	1	0	
				LP5810DDSDR	1	1	

5 Pin Configuration and Functions

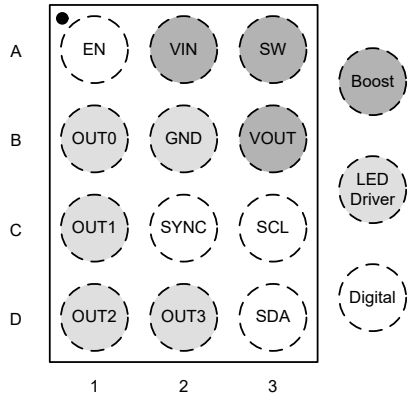


Figure 5-1. LP5811 YBH Package 12-Pin DSBGA Top View

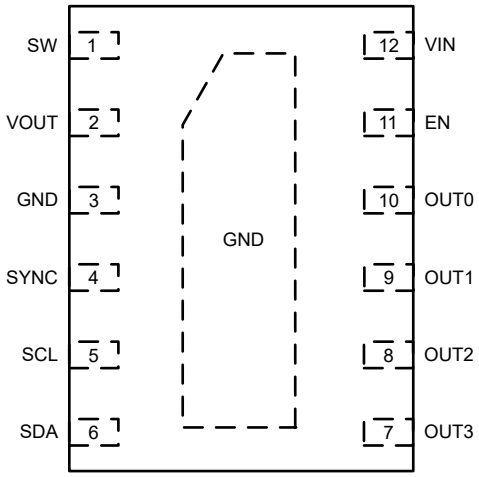


Figure 5-2. LP5811 DRR Package 12-Pin WSON Top View

Table 5-1. Pin Functions

PIN			TYPE(1)	DESCRIPTION
NAME	YBH	DRR		
EN	A1	11	I	Enable input of the integrated boost converter.
VIN	A2	12	P	Power supply of the device. A 10 µF capacitor is recommended to be connected between this pin with GND and be placed as close to the device as possible.
SW	A3	1	P	Switch pin of the integrated boost converter, which is connected to the drain of low-side power FET and source of high-side rectifier FET. Connect the inductor to this pin
OUT0	B1	10	O	Output 0 which contains current sink 0 and high-side scan FET 0. If not used, this pin must be floating.
GND	B2	3	G	Ground. Must be connected to the common ground plane
VOUT	B3	2	P	Boost converter output. A 22 uF capacitor is recommended to be connected between this pin with GND and be placed as close to the device as possible.
OUT1	C1	9	O	Output 1 which contains current sink 1 and high-side scan FET 1. If not used, this pin must be floating.
SYNC	C2	4	I/O	Synchronous between multiple devices. If not used, this pin can be connected to ground to save power.
SCL	C3	5	I	I^2C serial interface clock input.
OUT2	D1	8	O	Output 2 which contains current sink 2 and high-side scan FET 2. If not used, this pin must be floating.
OUT3	D2	7	O	Output 3 which contains current sink 3 and high-side scan FET 3. If not used, this pin must be floating.
SDA	D3	6	I/O	I^2C serial interface data input/output.

(1) P: Power Pin; I: Input Pin; I/O: Input/Output Pin; O: Output Pin.

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

		MIN	MAX	UNIT
Voltage range at terminals	VIN, SW, VOUT	–0.3	6	V
	SW spike at 10 ns	–0.7	8	V
	SW spike at 1 ns	–0.7	9	V
	OUT0, OUT1, OUT2, OUT3	–0.3	6	V
	EN, SCL, SDA, SYNC	–0.3	6	V
T_J	Junction temperature	–40	150	°C
T_{stg}	Storage temperature	–65	150	°C

(1) Operation outside the Absolute Maximum Ratings may cause permanent device damage. Absolute Maximum Ratings do not imply functional operation of the device at these or any other conditions beyond those listed under Recommended Operating Conditions. If used outside the Recommended Operating Conditions but within the Absolute Maximum Ratings, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins(1)	±4000	V
		Charged device model (CDM), per ANSI/ESDA/JEDEC JS-002, all pins(2)	±1000	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
V_{IN}	Input voltage range	0.5		5.5	V
V_{OUT}	Output voltage setting range	3		5.5	V
L	Effective inductance range	0.37	1	2.9	µH
C_{IN}	Effective input capacitance range	1	4.7		µF
C_{OUT}	Effective output capacitance range	4	10	1000	µF
OUT0, OUT1, OUT2, OUT3	Voltage on OUT0, OUT1, OUT2, OUT3 pins	0		5.5	V
EN, SCL, SDA, SYNC	Voltage on EN, SCL, SDA, SYNC pins	0		5.5	V
T_A	Ambient temperature	–40		85	°C
T_J	Operating junction temperature	–40		125	°C

6.4 Thermal Information

THERMAL METRIC(1)		LP5810/2		LP5811/3		UNIT
		YBH (DSBGA)	DSD (WSON)	YBH (DSBGA)	DRR (WSON)	
		9 PINS	8 PINS	12 PINS	12 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	113.1	50.8	92.1	47.5	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	0.6	51.1	0.4	45.1	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	33.9	22.9	25.9	20.9	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	0.2	1.1	0.2	0.7	°C/W

THERMAL METRIC(1)		LP5810/2		LP5811/3		UNIT
		YBH (DSBGA)	DSD (WSON)	YBH (DSBGA)	DRR (WSON)	
		9 PINS	8 PINS	12 PINS	12 PINS	
Ψ_{JB}	Junction-to-board characterization parameter	33.8	22.8	25.8	20.9	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	n/a	8.5	n/a	6.6	°C/W

(1) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report.

6.5 Electrical Characteristics

Unless specified otherwise, typical characteristics apply over the full ambient temperature range (–40°C < TA < +85°C), V_{IN} = 3.6 V, VOUT = 5 V, C_{IN} = 1 µF, C_{OUT} = 1 µF.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
Power Supply						
V_{IN}	Input voltage range		0.5		5.5	V
V_{IN_UVLO}	Under-voltage lockout threshold	V_{IN} rising		1.7	1.8	V
		V_{IN} falling		0.4	0.5	V
I_{SD}	Shutdown current into VIN and SW pin	IC disabled (EN = Low), V_{IN} = 3.6 V, T_A = 25°C		0.1	0.35	µA
I_{STB}	Standby current into VIN and SW pin	CHIP_EN = 0 (bit), Boost enabled (EN = High), V_{IN} = 3.6 V, VOUT set to 3 V, Pass-through mode		26	29	µA
	Standby current into VOUT pin	CHIP_EN = 0 (bit), Boost disabled (EN = Low), VIN no supply, VOUT force to 5 V		25	28	µA
I_{NOR}	Normal operation current into VIN and SW pin	CHIP_EN = 1 (bit), Boost enabled (EN = High), V_{IN} = 3.6 V, VOUT set to 3 V, Pass-through mode, I_{OUT0} = I_{OUT1} = I_{OUT2} = I_{OUT3} = 25.5 mA (MC = 0, DC = 255, PWM = 255)		0.45	0.65	mA
	Normal operation current into VOUT pin	CHIP_EN = 1 (bit), Boost disabled (EN = LOW), VOUT force to 3.6 V, I_{OUT0} = I_{OUT1} = I_{OUT2} = I_{OUT3} = 25.5 mA (MC = 0, DC = 255, PWM = 255)		0.4	0.6	mA
Boost Output						
V_{OUT}	Output voltage setting range		3		5.5	V
V_{OVP}	Output over-voltage protection threshold	V_{OUT} rising	5.5	5.7	5.9	V
V_{OVP_HYS}	Over-voltage protection hysteresis			0.2		V
t_{SS}	Soft startup time	From active EN to VOUT regulation. V_{IN} = 1.8 V, C_{OUT} = 22 µF, I_{VOUT} = 0 mA		450		µs
Boost Power Switch						
$R_{DS(on)}$	High-side MOSFET on resistance	V_{VOUT} = 5 V		140		mΩ
	Low-side MOSFET on resistance	V_{VOUT} = 5 V		60		mΩ
f_{SW}	Switching frequency	V_{IN} = 3.6 V, V_{OUT} set to 5.0 V, PWM mode		1		MHz
		V_{IN} = 1.0 V, V_{OUT} set to 5.0 V, PFM mode		0.5		MHz
I_{LIM_SW}	Valley current limit	V_{IN} = 3.6 V, V_{OUT} set to 5.0 V		1.6		A
I_{PRECHG}	Pre-charge current	V_{IN} = 3.6 V		350		mA
LED Driver Output						
I_{CS}	Constant current sink output range	V_{IN} = 3.6 V, V_{OUT} set to 5 V, MC = 0, manual_pwm_x = FFh (100% ON)	0.1		25.5	mA
		V_{IN} = 3.6 V, V_{OUT} set to 5 V, MC = 1, manual_pwm_x = FFh (100% ON)	0.2		51	mA

Unless specified otherwise, typical characteristics apply over the full ambient temperature range (–40°C < TA < +85°C), V_{IN} = 3.6 V, VOUT = 5 V, C_{IN} = 1 µF, C_{OUT} = 1 µF.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
I_{CS_LKG}	Constant current sink leakage current	V_{IN} = 3.6 V, OUTx = 1 V, manual_pwm_x = 0 (0%)		0.1	1	µA
I_{ERR_D2D}	Device to device current error, $I_{ERR\_D2D} = (I_{AVE}-I_{SET})/I_{SET}\times100\%$	All LEDs turn ON. Current set to 0.1 mA (max_current = 0, manual_dc_x = 01h, manual_pwm_x = FFh)	–5		5	%
		All LEDs turn ON. Current set to 0.2 mA (max_current = 1, manual_dc_x = 01h, manual_pwm_x = FFh)	–3		3	%
		All LEDs turn ON. Current set to 1 mA (max_current = 0, manual_dc_x = 0Ah, manual_pwm_x = FFh)	–5		5	%
		All LEDs turn ON. Current set to 1 mA (max_current = 1, manual_dc_x = 05h, manual_pwm_x = FFh)	–3		3	%
		All LEDs turn ON. Current set to 25.5 mA (max_current = 0, manual_dc_x = FFh, manual_pwm_x = FFh)	–5		5	%
		All LEDs turn ON. Current set to 51 mA (max_current = 1, manual_dc_x = FFh, manual_pwm_x = FFh)	–3		3	%
I_{ERR_C2C}	Channel to Channel current error $I_{ERR\_C2C} = (I_{OUTX}-I_{AVE})/I_{AVE}\times100\%$	All LEDs turn ON. Current set to 0.1 mA (max_current = 0, manual_dc_x = 01h, manual_pwm_x = FFh)	–5		5	%
		All LEDs turn ON. Current set to 0.2 mA (max_current = 1, manual_dc_x = 01h, manual_pwm_x = FFh)	–3		3	%
		All LEDs turn ON. Current set to 1 mA (max_current = 0, manual_dc_x = 0Ah, manual_pwm_x = FFh)	–5		5	%
		All LEDs turn ON. Current set to 1 mA (max_current = 1, manual_dc_x = 05h, manual_pwm_x = FFh)	–3		3	%
		All LEDs turn ON. Current set to 25.5 mA (max_current = 0, manual_dc_x = FFh, manual_pwm_x = FFh)	–5		5	%
		All LEDs turn ON. Current set to 51 mA (max_current = 1, manual_dc_x = FFh, manual_pwm_x = FFh)	–3		3	%
V_{HR}	LED driver output hearroom voltage	All LEDs turn ON. Current set to 25.5 mA (max_current = 0, manual_dc_x = FFh)		0.11	0.15	V
		All LEDs turn ON. Current set to 51 mA (max_current = 1, manual_dc_x = FFh)		0.21	0.28	V
f_{LED_PWM}	LED PWM frequency	pwm_fre = 0		24		kHz
		pwm_fre = 1		12		kHz
f_{OSC}	Internal oscillator frequency	vsync_out_en = 1		6		MHz
Logic Interface						
V_{EN_H}	EN logic high	V_{IN} > 1.8 V	1.2			V
V_{EN_L}	EN logic low	V_{IN} > 1.8 V			0.35	V
V_{IH_LOGIC}	High level input voltage of SDA, SCL, SYNC		1.4			V
V_{IL_LOGIC}	Low level input voltage of SDA, SCL, SYNC				0.4	V
V_{OH_LOGIC}	High level output voltage of SYNC		V_{VOUT} - 0.2			V

Unless specified otherwise, typical characteristics apply over the full ambient temperature range (–40°C < TA < +85°C), V_{IN} = 3.6 V, VOUT = 5 V, C_{IN} = 1 µF, C_{OUT} = 1 µF.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{OL_LOGIC}	Low level output voltage of SDA, SYNC				0.4	V
Protection						
T_{SD}	Thermal shutdown threshold for LED driver part	T_J rising		150		°C
	Thermal shutdown threshold for Boost converter part	T_J rising		155		°C
T_{SD_HYS}	Thermal shutdown hysteresis	T_J falling below T_{SD}		15		°C
V_{LOD_TH}	LED open detection threshold	Current set to 25.5 mA (max_current = 0, manual_dc_x = FFh)	70	90	110	mV
		Current set to 51 mA (max_current = 1, manual_dc_x = FFh)	150	180	220	mV
V_{LSD_TH}	LED short detection threshold	lsd_th = 00h	0.32 × VOUT	0.35 × VOUT	0.38 × VOUT	V
		lsd_th = 01h	0.42 × VOUT	0.45 × VOUT	0.48 × VOUT	V
		lsd_th = 10h	0.52 × VOUT	0.55 × VOUT	0.58 × VOUT	V
		lsd_th = 11h	0.62 × VOUT	0.65 × VOUT	0.68 × VOUT	V

6.6 Timing Requirements

Unless specified otherwise, typical characteristics apply over the full ambient temperature range (–40°C < TA < +85°C), V_{IN} = 3.6 V, V_{CC} = 5 V, C_{IN} = 1 µF, C_{OUT} = 1 µF.

I²C Timing Requirements		MIN	NOM	MAX	UNIT
Standard-mode					
f_{SCL}	SCL clock frequency	0		100	kHz
t_{HD_STA}	Hold time (repeated) START condition. After this period, the first clock pulse is generated.	4			µs
t_{LOW}	LOW period of the SCL clock	4.7			µs
t_{HIGH}	HIGH period of the SCL clock	4			µs
t_{SU_STA}	Set-up time for a repeated START condition	4.7			µs
t_{HD_DAT}	Data hold time	0			µs
t_{SU_DAT}	Data set-up time	250			ns
t_r	Rise time of both SDA and SCL signals			1000	ns
t_f	Fall time of both SDA and SCL signals			300	ns
t_{SU_STO}	Set-up time for STOP condition	4			µs
t_{BUF}	Bus free time between a STOP and START condition	4.7			µs
C_b	Capacitive load for each bus line			400	pF
Fast-mode					
f_{SCL}	SCL clock frequency	0		400	kHz
t_{HD_STA}	Hold time (repeated) START condition. After this period, the first clock pulse is generated.	0.6			µs
t_{LOW}	LOW period of the SCL clock	1.3			µs
t_{HIGH}	HIGH period of the SCL clock	0.6			µs
t_{SU_STA}	Set-up time for a repeated START condition	0.6			µs
t_{HD_DAT}	Data hold time	0			µs
t_{SU_DAT}	Data set-up time	100			ns
t_r	Rise time of both SDA and SCL signals			300	ns

Unless specified otherwise, typical characteristics apply over the full ambient temperature range (–40°C < TA < +85°C), V_{IN} = 3.6 V, V_{CC} = 5 V, C_{IN} = 1 µF, C_{OUT} = 1 µF.

I²C Timing Requirements		MIN	NOM	MAX	UNIT
t_f	Fall time of both SDA and SCL signals			300	ns
t_{SU_STO}	Set-up time for STOP condition	0.6			µs
t_{BUF}	Bus free time between a STOP and START condition	1.3			µs
C_b	Capacitive load for each bus line			400	pF
Fast-mode Plus					
f_{SCL}	SCL clock frequency	0		1000	kHz
t_{HD_STA}	Hold time (repeated) START condition. After this period, the first clock pulse is generated.	0.26			µs
t_{LOW}	LOW period of the SCL clock	0.5			µs
t_{HIGH}	HIGH period of the SCL clock	0.26			µs
t_{SU_STA}	Set-up time for a repeated START condition	0.26			µs
t_{HD_DAT}	Data hold time	0			µs
t_{SU_DAT}	Data set-up time	50			ns
t_r	Rise time of both SDA and SCL signals			120	ns
t_f	Fall time of both SDA and SCL signals			120	ns
t_{SU_STO}	Set-up time for STOP condition	0.26			µs
t_{BUF}	Bus free time between a STOP and START condition	0.5			µs
C_b	Capacitive load for each bus line			550	pF
Misc. Timing Requirements					
f_{CLK_EX}	VSYNC input clock frequency		6		MHz

6.7 Typical Characteristics

Unless specified otherwise, typical characteristics apply over the full ambient temperature range (–40°C < T_A < +85°C), V_{IN} = 3.6V, C_{IN} = 1µF, C_{OUT} = 1µF

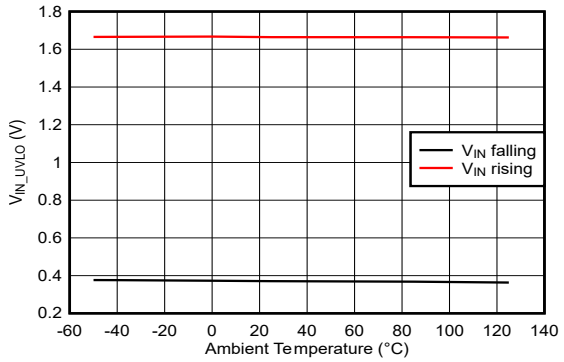


Figure 6-1. VIN UVLO Rising and Falling Thresholds

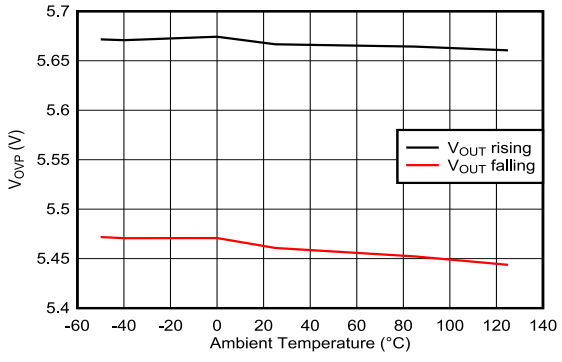


Figure 6-2. VOUT OVP Thresholds

6.7 Typical Characteristics (continued)

Unless specified otherwise, typical characteristics apply over the full ambient temperature range (–40°C < T_A < +85°C), V_{IN} = 3.6V, C_{IN} = 1µF, C_{OUT} = 1µF

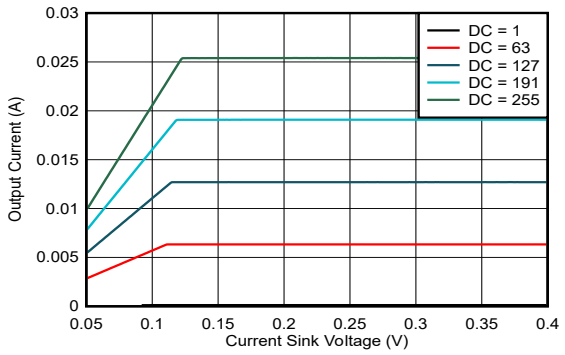


Figure 6-3. Current Sinks Voltage vs Current (MC = 0)

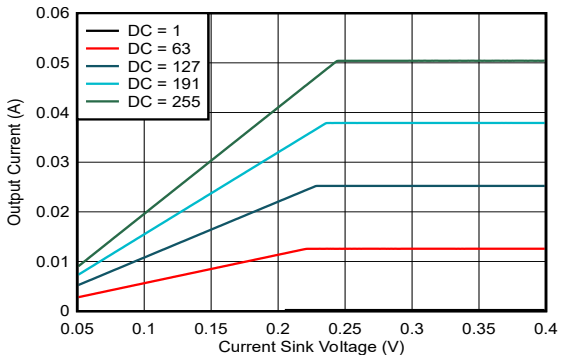


Figure 6-4. Current Sinks Voltage vs Current (MC = 1)

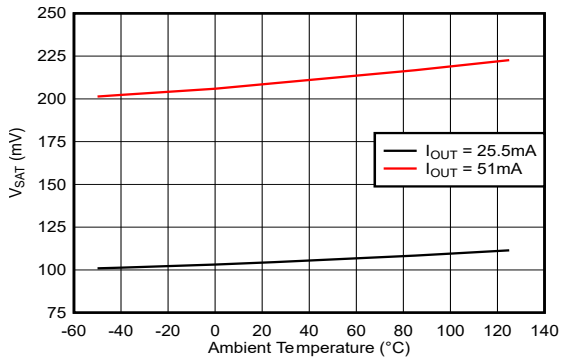


Figure 6-5. V_{SAT} vs Temperature

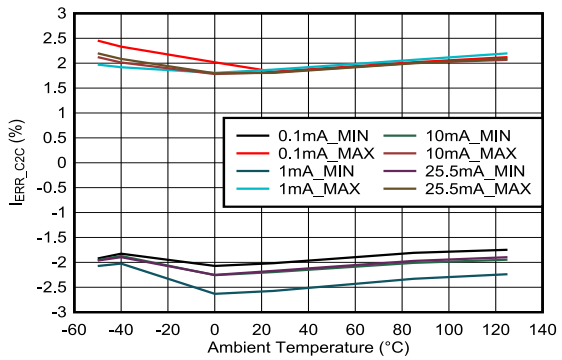


Figure 6-6. Channel-to-Channel Current Accuracy vs Temperature (MC = 0)

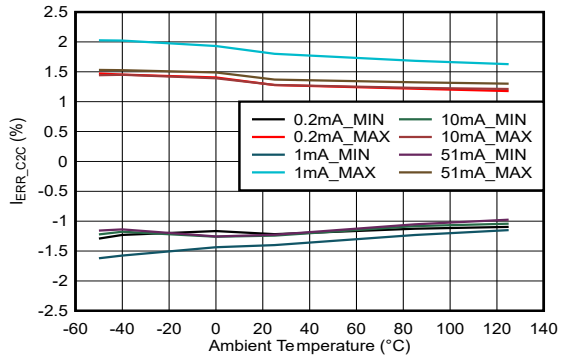


Figure 6-7. Channel-to-Channel Current Accuracy vs Temperature (MC = 1)

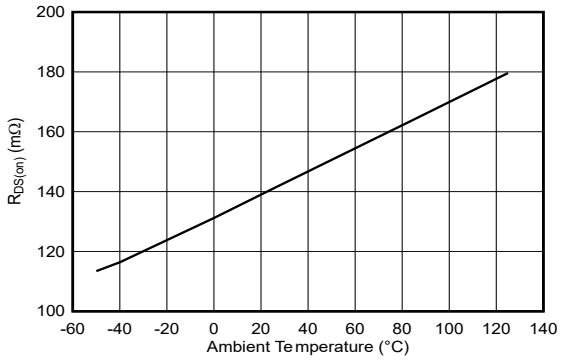


Figure 6-8. Boost High-Side MOSFET R_{DSON}

6.7 Typical Characteristics (continued)

Unless specified otherwise, typical characteristics apply over the full ambient temperature range (–40°C < T_A < +85°C), V_{IN} = 3.6V, C_{IN} = 1µF, C_{OUT} = 1µF

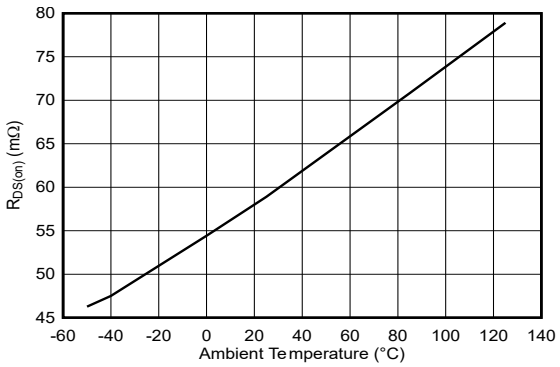


Figure 6-9. Boost Low-Side MOSFET R_{DSON}

7 Detailed Description

7.1 Overview

The LP5811 is a synchronous boost 4-channel RGBW LED driver with autonomous animation engine control. The device can support 1.8V minimum start-up voltage and 0.5V to 5.5V input voltage range during operation. The integrated synchronous boost converter can output 3V to 5.5V, to provide enough forward voltage of LEDs.

The LP5811 has ultra-low operation current at active mode, consuming about 0.4mA when LED maximum current setting is 25.5mA. If all LEDs are turned off, the device will enter standby state to reduce power consumption with data retained. When 'chip_enable' bit setting is 0, initial state is entered with minimum power consumption to save power.

The LP5811 supports both analog dimming and PWM dimming. In analog dimming, the output current of each LED can be adjusted with 256 steps. In PWM dimming, the integrated 8-bit configurable PWM generator enables smooth brightness dimming control. Optional exponential PWM dimming can be activated for individual LED to achieve a human-eye-friendly visual performance.

The LP5811 integrates autonomous animation engine, with no need for brightness control commands from controller. Each LED has an individual animation engine which can be configured through the related registers. The device can generate a 6 MHz clock signal, which synchronizes the lighting effects among multiple devices.

The LP5811 has 4 different material versions with different I^2C chip address. Up to 4 LP581x devices can be connected to the same I^2C bus and controlled individually. The LP5811 materials and corresponding chip addresses are shown in Section 4.

7.2 Functional Block Diagram

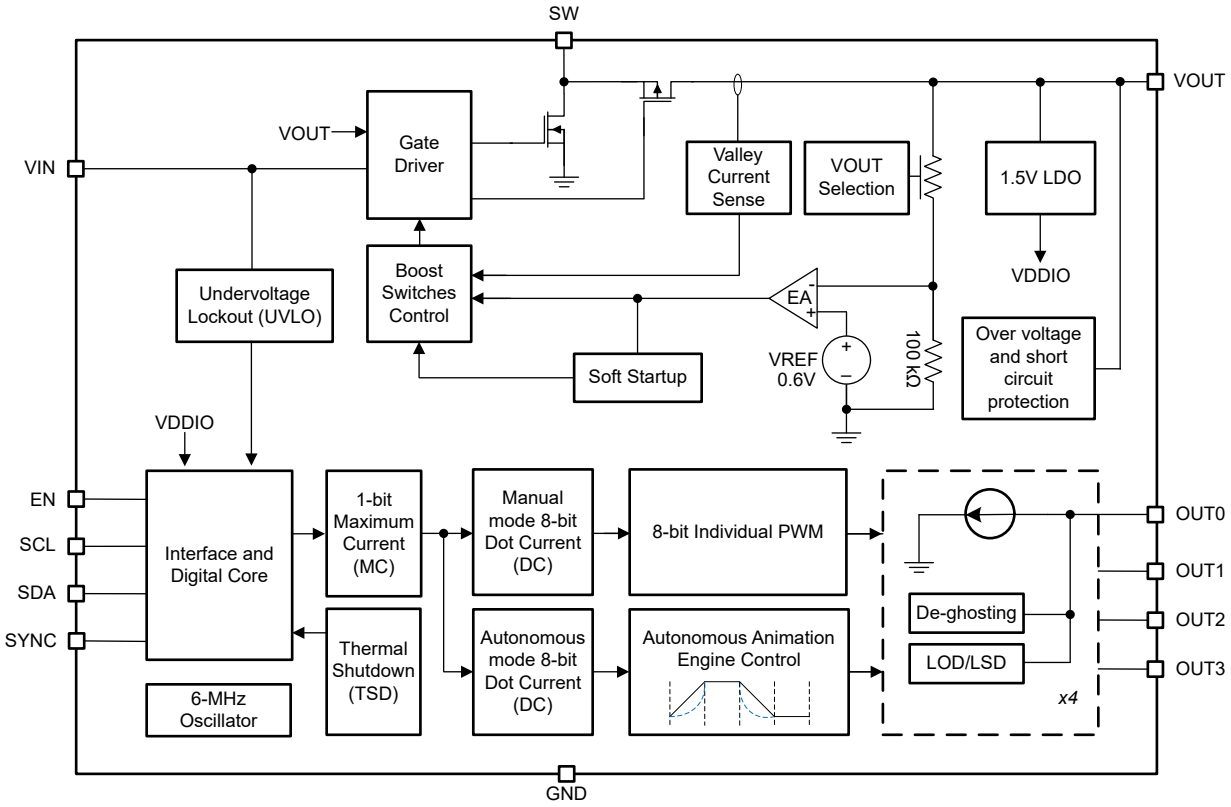


Figure 7-1. Functional Block Diagram

7.3 Feature Description

7.3.1 Synchronous Boost Converter

The integrated synchronous boost converter is designed to operate with 0.5V to 5.5V input voltage supply with 1.6A (typ.) valley switch current limit. The LP5811 operates at quasi-constant frequency pulse width modulation (PWM) mode, when driving moderate and heavy load. The switching frequency is 1MHz when the input voltage is above 1.5V. The frequency is reduced to 0.5MHz gradually when the input voltage decreases from 1.5V to 1V, and keeps at 0.5MHz when the input voltage is below 1V. At light load conditions, the boost converter operates at pulse frequency modulation (PFM) mode. During PWM operation, the converter works at adaptive constant on-time valley current mode to achieve excellent line regulation and load regulation, by which a smaller inductor and ceramic capacitors can be supported. Internal loop compensation simplifies the design complexity, and also minimizes the external components.

When powering up, the default output voltage is 3V. The output voltage can be configured at 'Dev_config_0' register from 3V to 5.5V, with 0.1V step. The integrated boost works as a general boost converter, which can power not only the LEDs driven by the device itself, but also other loads in the system.

7.3.1.1 Undervoltage Lockout

The LP5811 has a built-in undervoltage lockout (UVLO) circuit to make sure the device working properly. When the input voltage is above the UVLO rising threshold 1.8V, the boost of LP5811 can be enabled. After the LP5811 completes soft-start process and the output voltage rises above 2.2V, the LP5811 can work with the input voltage down to 0.5V. When the input voltage is below UVLO falling threshold 0.4V, the device shuts down.

7.3.1.2 Enable and Soft Start

When the input voltage is above the UVLO rising threshold 1.8V and the EN pin is pulled to a voltage above 1.2V, the boost of LP5811 is enabled and starts up. At the beginning, the LP5811 charges the boost output capacitor with a constant current when the output voltage is below 0.4V. When the output voltage is charged above 0.4V, the LP5811 has capability to drive 200mA load. After the output voltage reaches the input voltage, the boost of LP5811 starts switching, and the output voltage continually ramps up to default voltage 3V. The typical start-up time is 450μs from EN pulled high to output reaching default voltage 3V, at the application that input voltage is 2.5V, output effective capacitance is 10μF, and no load. When the EN is below 0.42V, the internal enable comparator turns the device into shutdown mode. In the shutdown mode, the device is entirely turned off and the output is disconnected from input power supply.

7.3.1.3 Switching Frequency

The LP5811 switches at quasi-constant 1MHz frequency when the input voltage is above 1.5V. When the input voltage is lower than 1.5V, the switching frequency is reduced gradually to 0.5MHz, which improves the boost efficiency and gets higher boost ratio. When the input voltage is below 1V, the switching frequency is fixed at quasi-constant 0.5MHz.

7.3.1.4 Current Limit Operation

The LP5811 uses a valley current limit sensing scheme. The inductor current is detected during the switching off-time, by sensing the voltage across the synchronous rectifier.

When the load current increases, such that the inductor current is above the current limit within the whole switching cycle , the off-time increases to discharge the inductor current. The current decreases below the limit before the next on-time. When the current limit is reached, the output voltage decreases if the load current continually increases.

The maximum continuous output current ($I_{OUT(CL)}$), before entering current limit (CL) operation, can be defined by Equation 1.

$$I_{OUT(CL)} = (1 - D) \times \left(I_{LIM} + \frac{1}{2} \Delta I_{L(P-P)}\right) \quad (1)$$

where

- D is the duty cycle
- $\Delta I_{L(P-P)}$ is the inductor ripple current

The duty cycle can be estimated by Equation 2.

$$D = 1 - \frac{V_{IN} \times \eta}{V_{OUT}} \quad (2)$$

where

- V_{OUT} is the output voltage of the boost converter
- V_{IN} is the input voltage of the boost converter
- η is the efficiency of the converter, use 90% for most applications

The peak-to-peak inductor ripple current is calculated by Equation 3.

$$\Delta I_{L(P-P)} = \frac{V_{IN} \times D}{L \times f_{SW}} \quad (3)$$

where

- L is the inductance value of the inductor
- f_{SW} is the switching frequency
- D is the duty cycle
- V_{IN} is the input voltage of the boost converter

7.3.1.5 Boost PWM Mode

The LP5811 uses a quasi-constant 1.0MHz frequency pulse width modulation (PWM) at moderate to heavy load current. Based on the input voltage to output voltage ratio, a circuit predicts the required on-time. At the beginning of the switching cycle, the main switching low-side FET is turned on. The input voltage is applied across the inductor and the inductor current ramps up. In this phase, the output capacitor is discharged by the load current. When the on-time expires, the low-side FET is turned off, and the high-side rectifier FET is turned on. The inductor transfers its stored energy to replenish the output capacitor and supplies the load. The inductor current declines because the output voltage is higher than the input voltage. When the inductor current hits the valley current threshold determined by the output of the error amplifier, the next switching cycle starts again.

The LP5811 has a built-in compensation circuit that can accommodate a wide range of input voltage, output voltage, inductor value, and output capacitor value for stable operation.

7.3.1.6 Boost PFM Mode

The LP5811 works at PFM to improve efficiency at light load. When the load current decreases, the inductor valley current set by the output of the error amplifier no longer regulates the output voltage. When the inductor valley current hits the low limit, the output voltage exceeds the setting voltage as the load current decreases further. When the feedback voltage hits the PFM reference voltage (0.6V typical), the LP5811 works at PFM. When the feedback voltage rises and hits the PFM reference voltage, the device continues switching for several cycles because of the delay time of the internal comparator — then it stops switching. The load is supplied by the output capacitor, and the output voltage declines. When the feedback voltage falls below the PFM reference voltage, after the delay time of the comparator, the device starts switching again to ramp up the output voltage. Figure 7-2 showes the waveform of voltage when the device works at PWM and PFM.

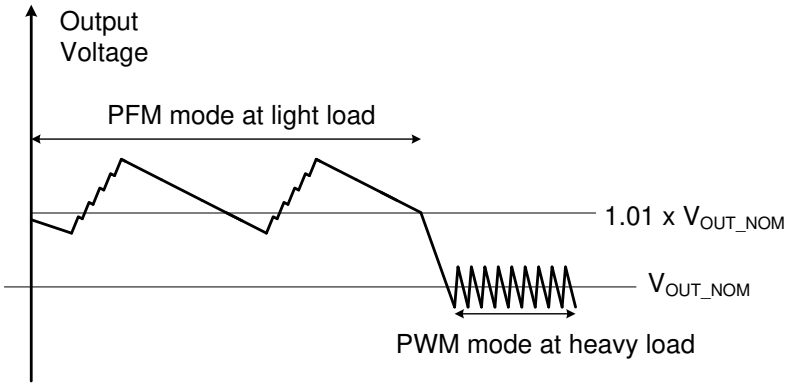


Figure 7-2. Output Voltage in PWM Mode and PFM

7.3.2 Analog Dimming

The current gain of each LED can be controlled by 2 methods to achieve analog dimming in the LP5811.

- Global 1-bit Maximum Current (MC) control for all LEDs without external resistor
- Individual 8-bit Dot Current (DC) control for each LED

The maximum output current I_{OUT_max} of each current sink can be programmed by the 1-bit max_current. The default value of max_current is 0h, which means the LED maximum current is set to 25.5mA in default.

Table 7-1. Maximum Current (MC) Bit Setting

1 bit Maximum Current (MC)		I_{OUT_MAX} (mA)
Binary	Decimal	
0 (default)	0 (default)	25.5 (default)
1	1	51

The LP5811 can individually adjust the peak current of each LED by using Dot Current (DC) function. The brightness deviation among the LED bins can be miminized, to achieve uniform display performance. The current is adjusted with 256 steps from 0 to 100% of $I_{OUT\_MAX.}$, which is programmed in an 8-bit register whose default value is 80h.

Table 7-2. Dot Current (DC) Bits Setting

8-bits Dot Current (DC) Register		Ratio of I_{OUT_MAX}
Binary	Decimal	
0000 0000	0	0%
0000 0001	1	0.39%
0000 0010	2	0.78%
---	---	---
1000 0000 (default)	128 (default)	50.2% (default)
---	---	---
1111 1101	253	99.2%
1111 1110	254	99.6%
1111 1111	255	100%

By configuring the MC and DC, the peak current of each current sink can be calculated as Equation 4:

$$I_{OUT}\left(mA\right) = I_{OUT\_max} \times \frac{DC}{255} \quad (4)$$

The average current of each LED in TCM drive mode and mix drive mode is shown as Equation 5:

$$I_{AVE}\left(mA\right) = \frac{I_{OUT}}{N} \times \frac{DC}{255} \times D_{PWM} \quad (5)$$

- N is the total scan number setting.
- D_{PWM} is the PWM duty.

7.3.3 PWM Dimming

The LP5811 supports 8-bit PWM dimming with 24kHz or 12kHz frequency, which is configured by 'PWM_Fre' bit in Dev_config_1 register. An internal 6MHz oscillator is used to generate the PWM clock. SYNC pin can be configured as PWM clock input or output by configure 'vsync_out_en' bit in Dev_Config_11 register. If multiple LP5811 are used in the system with autonomous animation engine control, all devices can refer the same clock signal, which comes from one of LP5811 or external controller, to avoid animation mismatch in long time operation.

Each LED can be configured into 3 different PWM alignment phases: Forward, Middle, and Backward. The alignment phase of each LED is set by 'phase_align' bits in Dev_Config_7 to Dev_Config_10 registers. By turning on the LEDs in different phase, the peak current load from boost or the system power supply is greatly decreased. The input current ripple and ceramic-capacitor audible ringing can also be reduced. Figure 7-3 shows the PWM alignment phases. In the forward alignment, the rising edge of PWM pulse is fixed at the beginning of PWM period. In the middle alignment, the middle point of PWM pulse is fixed at the middle of PWM period, while the pulse spreads to both directions. In the backward alignment, the falling edge of PWM pulse is fixed at the end of PWM period.

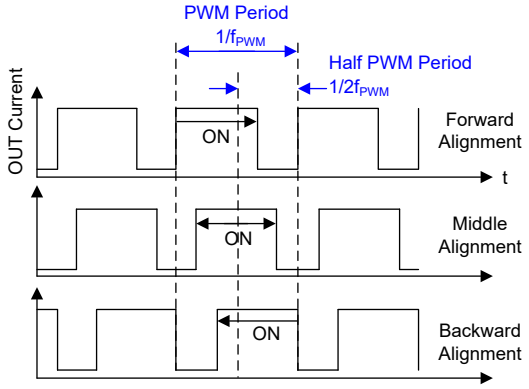


Figure 7-3. PWM Alignment Scheme

The LP5811 allow users to configure the dimming scale as exponential curve or linear curve, through the ‘exp_en’ bits in Dev_Config_5 and Dev_Config_6 registers. A human-eye-friendly visual performance can be achieved by using the internal exponential scale. The linear scale has great linearity between PWM duty cycle and PWM setting value, which provides flexible approach for external controlled gamma correction algorithm. The 8-bit linear and exponential curves are shown as Figure 7-4.

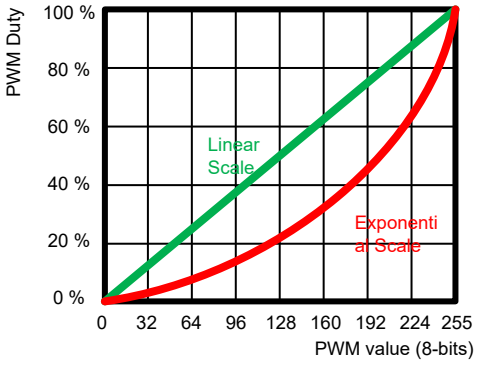


Figure 7-4. Linear and Exponential PWM Dimming Curves

7.3.4 Autonomous Animation Engine Control

The LP5811 supports both manual mode and autonomous mode to control the DC and PWM of each LED. In manual mode, the LEDs are directly controlled by the related configuration registers and reflect the value immediately. In autonomous mode, the autonomous animation engine is applied for each LED, which can realize vivid lighting effects without external processor control. The animation engine pattern is composed by 3 animation engine units (AEU) and 2 animation pause units (APU) for complex and flexible control. One AEU is formed by 4 slopers, which is used for fading effect.

After setting up all animation engine pattern configurations, sending start_cmd to the device can let the animation running autonomously, to free external controller real-time loading. The PWM value and unit status of each LED can be read from PWM_value registers and pattern_status registers. To make sure the precision of reading results, sending pause_cmd to pause the animation firstly is recommended.

7.3.4.1 Animation Engine Pattern

Each LED of the LP5811 has own animation engine, to achieve premium visual lighting effects. One whole animation engine pattern is defined as Figure 7-5. 3 animation engine units (AEU) and 2 animation pause units (APU) compose the animation engine pattern. AEU2 and AEU3 can be skipped by setting the playback times to 0. The LED current of each LEDs in the autonomous mode is set through the Autonomous_DC registers.

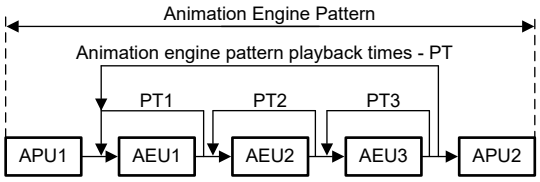


Figure 7-5. Animation engine pattern

The whole animation pattern includes two APUs and three AEUs with several playback times:

- APUx (x = 1, 2): Animation pause unit, each unit includes one timing value T.
- AEUx (x = 1, 2, 3): Animation engine unit, including 5 PWM values PWM1 to PWM5 and 4 time values T1 to T4.
- PT: Playback times of AEU1+AEU2+AEU3, which has 2-bit value to set 0/1/2/Infinite times.
- PTx: Playback times of AEUx (x=1/2/3), which has 2-bit value to set 0/1/2/Infinite times.

7.3.4.2 Sloper

Sloper is the basic element to achieve autonomous fade-in and fade-out animations. It can achieve 256 steps fade-in or fade-out effects from 'PWM_Start' to 'PWM_End' within a target time period T as Figure 7-6. The 8-bit PWM steps, which is configurable in animation pattern PWM setting registers, help to achieve extremely smooth effects. Exponential dimming curve can also be supported in the sloper.

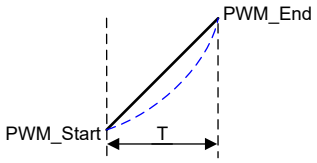


Figure 7-6. Sloper curve demonstration

The programable time T is selectable from 0 to around 8s with 16 levels shown in Table 7-3.

Table 7-3. Programable time options

Register value	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	Ah	Bh	Ch	Dh	Eh	Fh
Time (Typ.)	0 s	0.09 s	0.18 s	0.36 s	0.54 s	0.80 s	1.07 s	1.52 s	2.06 s	2.50 s	3.04 s	4.02 s	5.01 s	5.99 s	7.06 s	8.05 s

7.3.4.3 Animation Engine Unit (AEU)

The AEU is the most important unit to achieve autonomous animation effects. One AEU is formed by 4 slopers. There are 5 PWM values and 4 time values can be configured in the AEU. Each PWMx (x = 1, 2,…, 5) can be arbitrarily programmed from 0 to 255, The Tx (x = 1, 2, 3, 4) is selectable from 0 to 8 s with 16 levels referring to Table 7-3. If two adjacent PWM values are equal, the brightness keeps unchange within the time setting. When a Tx is set to 0, this sloper is skipped. To avoid flicker happens due to PWM value suddenly changes, the begin and end PWM of this sloper need to be the same.

Typical breathing effect example is illustrated as Figure 7-7.

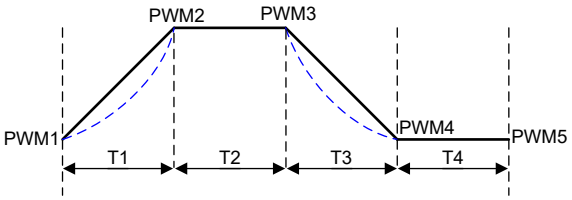


Figure 7-7. Animation engine unit - Example 1

Advanced breathing effect example is shown in Figure 7-8. 2 different fading speeds are set in the PWM rising and falling phases, to achieve a complex animation.

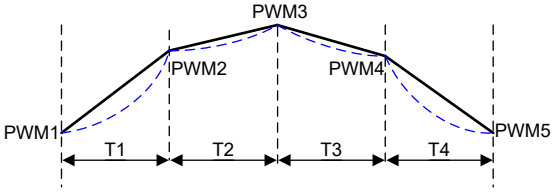


Figure 7-8. Animation engine unit - Example 2

7.3.4.4 Animation Pause Unit (APU)

The APU is defined as the pausing time at the beginning and the end of the animation pattern. The APU contains 1 time value which is selectable from 0 to 8s with 16 levels referring to Table 7-3. If the value is set as 0, the APU is skipped. The brightness of APU1 uses the PWM1 value of the AEU following the APU1, while the brightness of APU2 uses the PWM5 value of the AEU in front of APU2. One animation pattern example is shown in Figure 7-9. Only AEU2 is enabled in the pattern, so that the brightness of APU1 uses the PWM1 value of AEU2, and the brightness of APU2 uses PWM5 value of AEU2.

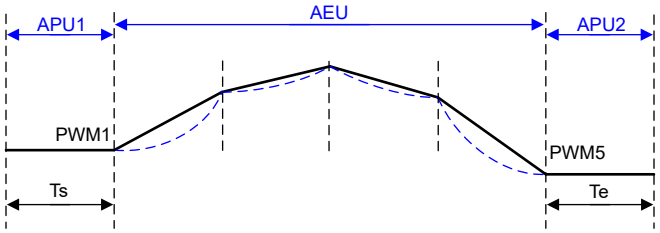


Figure 7-9. APU example

7.3.5 Protections and Diagnostics

7.3.5.1 Overvoltage Protection

The boost of LP5811 has an output overvoltage protection (OVP) to protect the device. When the output voltage is above 5.7V, the boost stops switching. Once the output voltage falls 0.1V below the OVP threshold, the boost resumes operating again.

7.3.5.2 Output Short-to-Ground Protection

The boost of LP5811 starts to limit the boost current when the boost output voltage is below 1.8V. The lower the boost output voltage reaches, the smaller the output current decreases. When the VOUT pin is short to ground and the boost output voltage is less than 0.4V, the output current is limited to approximately 350mA. Once the short circuit is released, the LP5811 goes through the soft start-up again to the regulated output voltage.

7.3.5.3 LED Open Detections

The LP5811 integrates LED open detection (LOD) for the fault caused by any open LED. The threshold for LOD is 90 mV when max current is set as 25.5 mA, and 180 mV when max current is set as 51 mA. To have enough detection time, LOD can only be performed when the PWM setting of this LED is above 25. If the voltage on the cathode of this LED is lower than the LOD threshold in continuously 3 cycles, LED open of this LED is reported to the corresponding LOD_status register.

The LOD flags can be cleared by writing 1h to 'lod_clear' bit in Fault_Clear register. If the LED open status is removed, the related 'lod_status' bit is set to 0 automatically.

The 'lod_action' bit in Dev_config_12 register can determine the action once open fault is detected. When the 'lod_action' bit is set to 1h, the dot where LED open happens is turned off to avoid any unpredictable issue. When the 'lod_action' bit is 0, no additional action is taken after LOD is detected. LED open fault detection and action is only executed in NORMAL state.

7.3.5.4 LED Short Detections

The LP5811 integrates LED short detection (LSD) for the fault caused by any short LED. The threshold of LSD is able to configure from (0.35 × V_{OUT}) V to (0.65 × V_{OUT}) V by configuring lsd_threshold in Dev_config_12 register. To have enough detection time, LSD can only be performed when the PWM setting of this LED is above 25. If the voltage on the cathode of this LED is higher than the LSD threshold in continuously 3 cycles, LED short of this LED is reported to the corresponding LSD_status register.

The LSD flags can be cleared by writing 1h to lsd_clear in Fault_CLR register. If the LED short status is removed, the related lsd_status bit is set to 0 automatically.

The 'lsd_action' bit in Dev_config_12 register can determine the reaction once open fault is detected. When the 'lsd_action' bit is set to 1h, all LEDs are turned off which is called one fails all fail (OFAF) action, to prevent potential damage caused by the short issue. The device enters to STANDBY state after sending 'lsd_clear' command. When the 'lsd_action' bit is 0, no additional action is taken after LSD is detected. LSD detecion is only executed in NORMAL state.

7.3.5.5 Thermal Shutdown

The LED driver of LP5811 goes into thermal shutdown state once the junction temperature exceeds 150°C. All LEDs turn off to avoid damaging the device. When the junction temperature drops below the thermal shutdown recovery temperature 130°C, the LED driver starts operating again.

The boost converter of LP5811 stops switching and is shutdown once the junction temperature exceeds 155°C, and the power on reset of the LED driver part is also triggered. When the junction temperature drops below the thermal shutdown recovery temperature, typically 130°C, the LP5811 enters shutdown state, and then the device needs to be configured again for normal operations.

7.4 Device Functional Modes

The Figure 7-10 shows the main state machine of the LED driver.

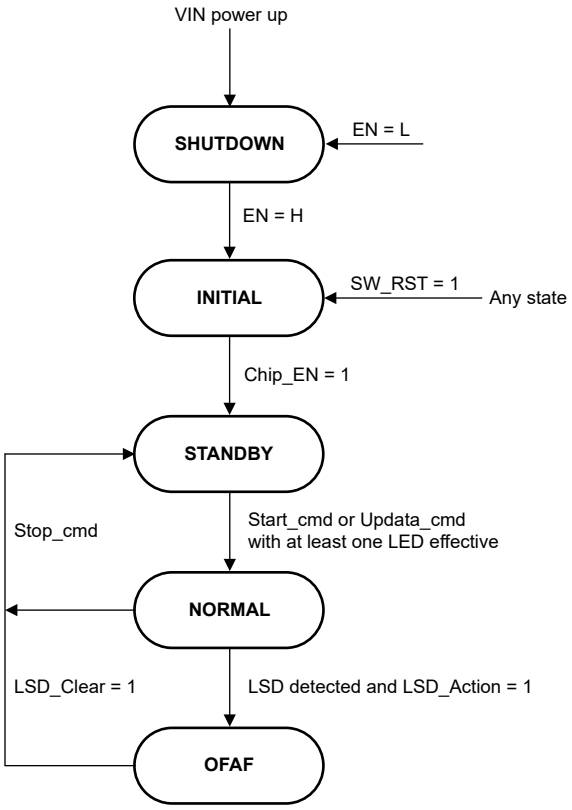


Figure 7-10. LP5811 Functional Modes

- SHUTDOWN: The device enters into SHUTDOWN after VIN power up.
- INITIAL: The device enters into INITIAL state from SHUTDOWN when EN is pulled high.
- STANDBY: The device enters into STANDBY state from INITIAL when Chip_EN is set to 1. The device can also enter into STANDBY from NORMAL when no LED is effective, or Stop_cmd is received, or from OFAF when LSD_Clear = 1.
- NORMAL: The device enters NORMAL state from STANDBY when one or more LEDs are effective: for manual mode, at least one LED is enable (PWM and DC setting is not 0); for autonomous mode, at lease one LED is enable and Start_cmd is received.
- OFAF: The device enters OFAF (one fail all fail) state when LED short is detected and LSD_Action =1. In OFAF mode, all LEDs are turned off. Once LSD_Clear is writen to 1, the device enters back to STANDBY state.

7.5 Programming

The LP5811 is compatible with I²C standard specification. The device supports standard mode (100-kHz maximum), fast mode (400-kHz maximum), and fast plus mode (1-MHz maximum). The device has 4 different chip address versions, which allows connecting up to four parallel devices in one I²C bus.

I²C Data Transactions

The data on SDA line must be stable during the HIGH period of the clock signal (SCL). In other words, state of the data line can only be changed when clock signal is LOW. START and STOP conditions classify the beginning and the end of the data transfer session. A START condition is defined as the SDA signal transitioning from HIGH to LOW while SCL line is HIGH. A STOP condition is defined as the SDA transitioning from LOW to HIGH while SCL is HIGH. The bus leader always generates START and STOP conditions. The bus is considered to be busy after a START condition and free after a STOP condition. During data transmission, the bus leader can generate repeated START conditions. First START and repeated START conditions are functionally equivalent.

Each byte of data has to be followed by an acknowledge bit. The acknowledge related clock pulse is generated by the leader. The leader releases the SDA line (HIGH) during the acknowledge clock pulse. The device pulls down the SDA line during the 9th clock pulse, signifying an acknowledge. The device generates an acknowledge after each byte has been received.

There is one exception to the acknowledge after every byte rule. When the leader is the receiver, the receiver must indicate to the transmitter an end of data by not acknowledging (*negative acknowledge*) the last byte clocked out of the follower. This negative acknowledge still includes the acknowledge clock pulse (generated by the leader), but the SDA line is not pulled down.

I²C Data Format

The address and data bits are transmitted MSB first with 8-bits length format in each cycle. Each transmission is started with Address Byte 1, which are divided into 5 bits of the chip address, 2 higher bits of the register address, and 1 read/write bit. The other 8 lower bits of register address are put in Address Byte 2.The device supports both independent mode and broadcast mode. The auto-increment feature allows writing / reading several consecutive registers within one transmission. If not consecutive, a new transmission must be started. The Bit 4 and Bit 3 are determined by the device, which can refer to Section 4.

Table 7-4. I²C Data Format

Address Byte1	Chip Address					Register Address		R/W
	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Independent	1	0	1	Bit 4	Bit 3	9th bit	8th bit	R: 1 W: 0
Broadcast	1	1	0	1	1			
Address Byte2	Register Address							
	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
	7th bit	6th bit	5th bit	4th bit	3rd bit	2nd bit	1st bit	0 bit

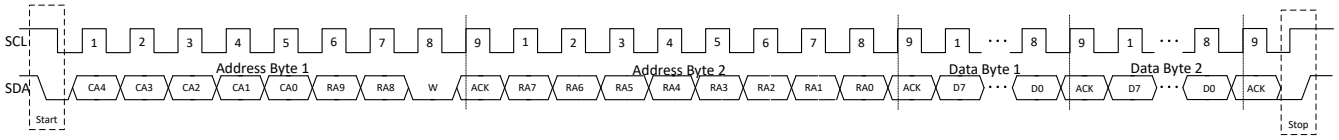


Figure 7-11. I²C Write Timming

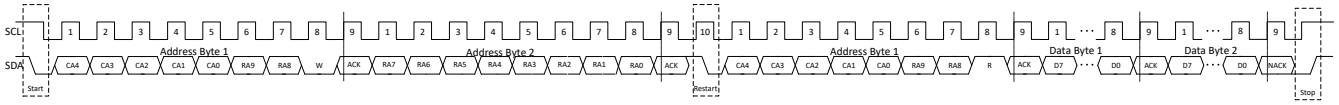


Figure 7-12. I²C Read Timing

7.6 Register Maps

This section provides a summary of the LP5811 register maps.

Table 7-5. Register Section/Block Access Type Codes

Access Type	Code	Description
Read Type		
R	R	Read
RC	R C	Read to Clear
R-0	R -0	Read Returns 0s
Write Type		
W	W	Write
W0CP	W 0C P	W 0 to clear Requires privileged access
Reset or Default Value		
-n		Value after reset or the default value

Table 7-6. LP5811 Registers Map

Register Group	Register Acronym	Address(Hex.)	Function	Type
ChipEN	Chip_en	000	Chip enable	R/W
CONFIG	Dev_config0 ~ Dev_config12	001 ~ 00D	Device configuration registers	R/W
Update CMD	Update_cmd	010	Configuration update command: CONFIG registers will ONLY be effective by sending this command	R/W
Start CMD	Start_cmd	011	Autonomous control start command or restart with the latest setting	R/W
Stop CMD	Stop_cmd	012	LED driver stop command, LED driver goes to INITIAL state with this command from all the other states	R/W
Pause CMD	Pause_cmd	013	Autonomous control pause command	R/W
Continue CMD	Continue_cmd	014	Autonomous control continue command	R/W
LED EN	LED_EN1	020	LED enable registers	R/W
Fault CLR	Fault_Clear	022	Fault clear registers to clear TSD/LOD/LSD faults	R/W
RESET	Reset	023	Software reset	W
DC_Manual	DC0 ~ DC3	030 ~ 033	LED current setting at manual mode	R/W
PWM_Manual	PWM0 ~ PWM3	040 ~ 043	LED PWM setting at manual mode	R/W
DC_Auto	DC_Auto0 ~ DC_Auto3	050 ~ 053	LED current setting at autonomous mode	R/W
LED0 AEP	Tp, PT, PWM1 ~ PWM5, T1 ~ T4	080 ~ 099	LED0 Animation Engine Pattern parameters	R/W
LED1 AEP	Tp, PT, PWM1 ~ PWM5, T1 ~ T4	09A ~ 0B3	LED1 Animation Engine Pattern parameters	R/W
LED2 AEP	Tp, PT, PWM1 ~ PWM5, T1 ~ T4	0B4 ~ 0CD	LED2 Animation Engine Pattern parameters	R/W
LED3 AEP	Tp, PT, PWM1 ~ PWM5, T1 ~ T4	0CE ~ 0E7	LED3 Animation Engine Pattern parameters	R/W

Table 7-6. LP5811 Registers Map (continued)

STATUS	TSD_Config_Status	300	TSD status and Configuration error indication register	R
	LOD_Status1 ~ LOD_Status2	301 ~ 302	LOD status registers	R
	LSD_Status1 ~ LSD_Status2	303 ~ 304	LSD status registers	R
	PWM_Internal0 ~ PWM_Internal_D2	305 ~ 314	Internal PWM values for LED0 ~ LED_D2	R
	PATTERN_Status1 ~ PATTERN_Status8	315 ~ 31C	AEP status registers to indicate pattern progress for LED0 ~ LED_D2	R

8 Application and Implementation

Note

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation to confirm system functionality.

8.1 Application Information

The LP5811 is a 4-ch synchronous boost RGB LED driver with autonomous animation engine control. The device is ideal to support battery-powered applications with 0.5V to 5.5V input voltage range. The LP5811 has ultra-low operation current at active mode, and it only consumes 0.4mA when LED current is set at 25mA.
In battery powered applications like e-tag, earbud, e-cigarettes, VR headset, RGB mouse, smart speaker, and other handheld devices, LP5811 is ideal to provide premimum LED lighting effects with low power consumption and small package.

8.2 Typical Application

8.2.1 Application

Figure 8-1 shows an example of typical application, which uses one LP5811 to drive RGBW LEDs through I^2C communication.

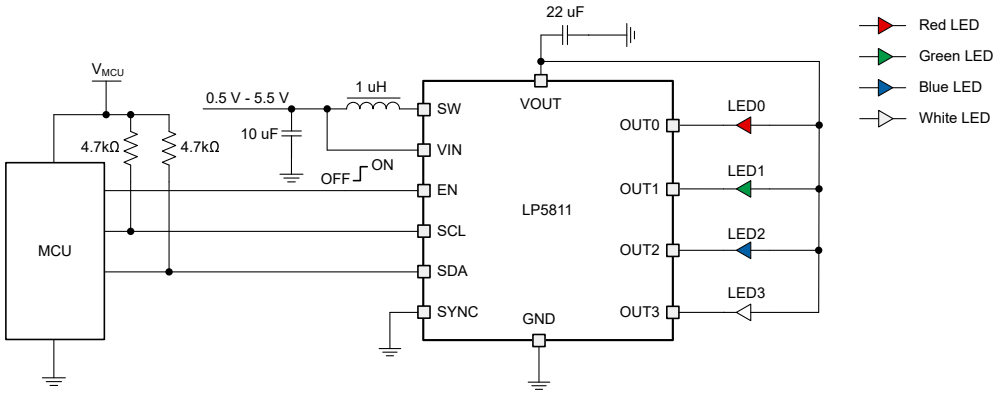


Figure 8-1. Typical Application - LP5811 Driving RGBW LEDs

8.2.2 Design Parameters

Design Parameters shows the typical design parameters of Figure 8-1.

Table 8-1. Design Parameters

PARAMETER	VALUE
Input voltage	3.6V to 4.2V by one Li-on battery cell
Output voltage	4.5V
Inductor	1μH
Output capacitor	22μF
LED count	4
LED maximum average current (red, green, blue, white)	51mA, 40mA, 40mA, 40mA
LED PWM frequency	24kHz

8.2.3 Detailed Design Procedure

This section will showcase the detailed design procedures for LP5811 including boost components selection, LED driver manual and autonomous modes application examples.

8.2.3.1 Inductor Selection

The inductor is the most important component in power regulator design, which affects steady-state operation, transient behavior, and loop stability. There are three important inductor specifications, inductor value, saturation current, and dc resistance (DCR).

The integrated boost converter in LP5811 is designed to work with inductor values between 0.37μH and 2.9μH. 1μH is recommended in typical application. The inductor peak current can be calculated by Equation 8. Using the minimum input voltage, maximum output voltage, and maximum load current of the application can calculate the worst case.

In a boost regulator, the inductor dc current can be calculated by Equation 6.

$$\Delta I_{L(DC)} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times \eta} \quad (6)$$

where

- V_{OUT} is the output voltage of the boost converter
- I_{OUT} is the output current of the boost converter
- V_{IN} is the input voltage of the boost converter
- η is the power-conversion efficiency, use 90% for most cases

The inductor ripple current is calculated by Equation 7.

$$\Delta I_{L(P-P)} = \frac{V_{IN} \times D}{L \times f_{SW}} \quad (7)$$

where

- D is the duty cycle, which can be calculated by
- L is the inductance value of the inductor
- f_{SW} is the switching frequency
- V_{IN} is the input voltage of the boost converter

Therefore, the inductor peak current is calculated by Equation 8.

$$\Delta I_{L(P)} = \Delta I_{L(DC)} + \frac{\Delta I_{L(P-P)}}{2} \quad (8)$$

Inductor peak-to-peak current is recommended to be designed less than 40% of the average inductor current, with maximum output current setting. Large inductor value reduces the magnetic hysteresis losses in the inductor and improves EMI performance with small inductor ripple, but the load transient response time increases. The saturation current of the inductor must be higher than the calculated peak inductor current.

8.2.3.2 Output Capacitor Selection

The output capacitor is selected to meet the requirements of output ripple and loop stability. The ripple voltage is related to capacitor capacitance and equivalent series resistance (ESR). Assuming a ceramic capacitor with zero ESR, the minimum capacitance for a given ripple voltage can be calculated by Equation 9.

$$C_{OUT} = \frac{I_{OUT} \times D_{MAX}}{f_{SW} \times V_{RIPPLE}} \quad (9)$$

where

- D_{MAX} is the maximum switching duty cycle
- V_{RIPPLE} is the peak-to-peak output ripple voltage
- I_{OUT} is the maximum output current
- f_{SW} is the switching frequency

The ESR impact on the output ripple must be considered if tantalum or aluminum electrolytic capacitors are used. The output peak-to-peak ripple voltage caused by the ESR of the output capacitors can be calculated by Equation 10.

$$V_{RIPPLE(ESR)} = I_{L(P)} \times R_{ESR} \quad (10)$$

The derating of a ceramic capacitor under dc bias voltage, aging, and ac signal need to be considered during design. For example, the dc bias voltage can significantly reduce capacitance. A ceramic capacitor can lose more than 50% of capacitance at the rated voltage. Therefore, enough the voltage rating margin must be left to get adequate capacitance at the required output voltage. Increasing the output capacitor can make the output ripple voltage smaller in PWM mode.

TI recommends using the X5R or X7R ceramic output capacitor in the range of 4µF to 1000µF effective capacitance. 10µF effective capacitance is recommended in typical application, which means around 22µF rated capacitance. If the output capacitor is below the range, the boost regulator can potentially become unstable.

8.2.3.3 Input Capacitor Selection

Multilayer X5R or X7R ceramic capacitors are excellent choices for the input decoupling of the integrated boost converter, because of the extremely low ESR and small footprint. Input capacitors must be located as close as possible to the device. While a 10µF input capacitor is sufficient for most applications, large capacitance is used to reduce input current ripple. When the input power is supplied through long wire and only ceramic capacitor is put, the load step at the output induces ringing at the VIN pin. This ringing couples back to the output and influence loop stability or even damage the device. In this circumstance, placing additional bulk capacitance (tantalum or aluminum electrolytic capacitor) between ceramic input capacitor and the power supply can reduce the ringing

8.2.3.4 Program Procedure

After VIN powering up, the boost converter can be enabled by pulling EN to High. After around 1ms for boost output and internal oscillator stable, the device can be initialized by configuring chip_en = 1 after executing I^2C slave addressing. Then the CONFIG registers can be set to the excepted configuration. After updating the CONFIG registers, one update command must to be sent to make the configuration effective. Either manual mode or autonomous mode can be seleted for each LED. A new configuration is only effective once update command is received.

The detailed program procedure is illustrated as:

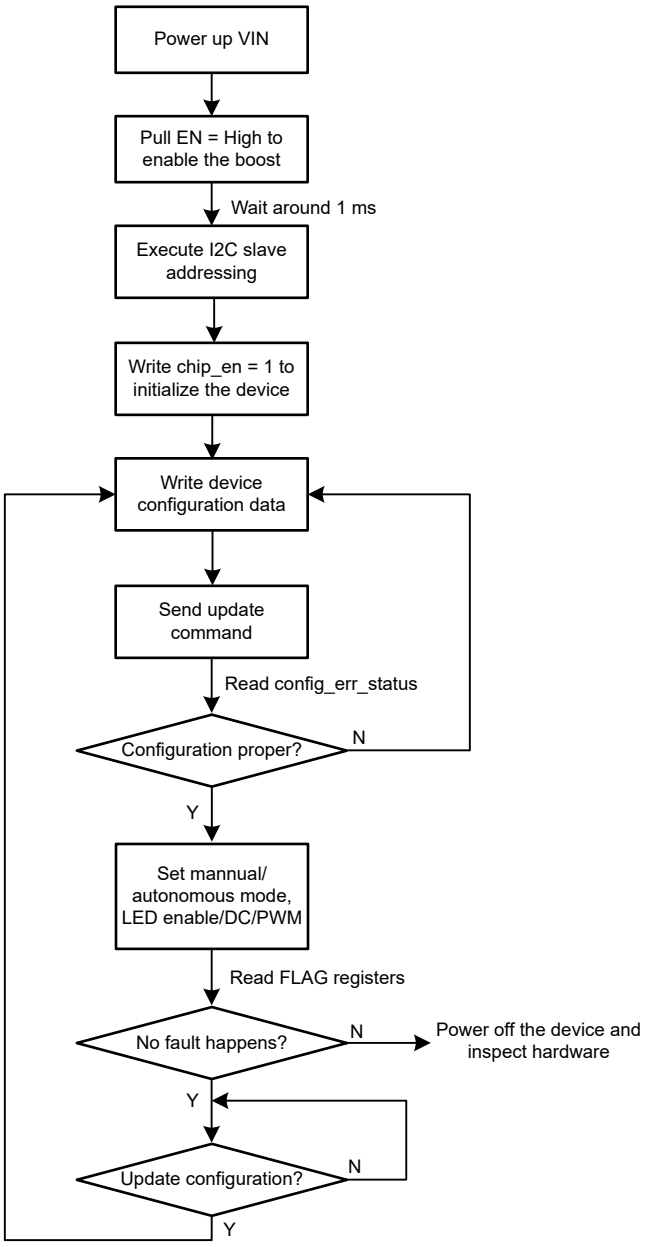


Figure 8-2. Program Procedure

8.2.3.5 Programming Example

To get the design parameters in Section 8.2.2, the following program steps can be referred.

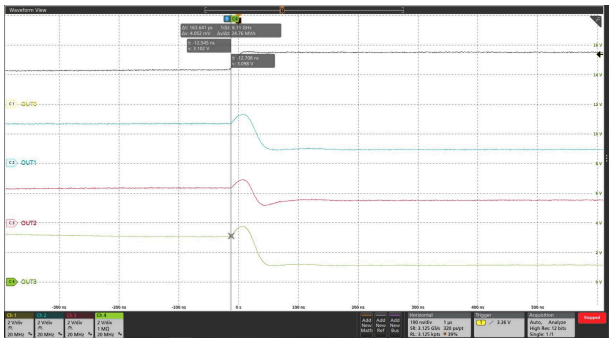
After VIN powering up, the boost converter being enabled by pulling EN to High and waiting around 1 ms,

1. Execute I^2C slave addressing, for details refer to the sample code
2. Set chip_en = 1 to enable the device (**Write 01h to register 000h**)
3. Set boost_vout = Fh to set 4.5V boost output voltage, and max_current = 1h to set 51mA maximum output LED current. (**Write 1Fh to register 001h**)
4. Set lsd_threshold = 3h is recommended to avoid incorrect LSD detection. (**Write 0Bh to register 00Dh**)

   Leave the PWM frequency, manual or autonomous mode, linear or exponential dimming curve, phase align method, vsync mode, blank time as default. (In other application requirements, these functions can be set)
5. Send update command to complete configuration settings (**Write 55h to register 010h**)
6. Read back config_err_status to check if the configuration is proper (**Read register 300h**)
7. Enable all 4 LEDs (**Write 0Fh to register 020h**)
8. Set 51 mA peak current for red LEDs, 40 mA peak current for green, blue and white LEDs (**write FFh to register 30h, write CCh to registers 031h - 033h**)
9. Set 100% duty cycle to illuminate the LEDs (**Write FFh to registers 040h - 043h**)

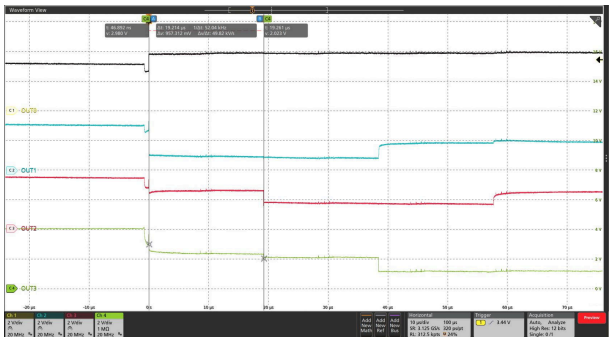
8.2.4 Application Performance Plots

The following figures show the application performance plots.



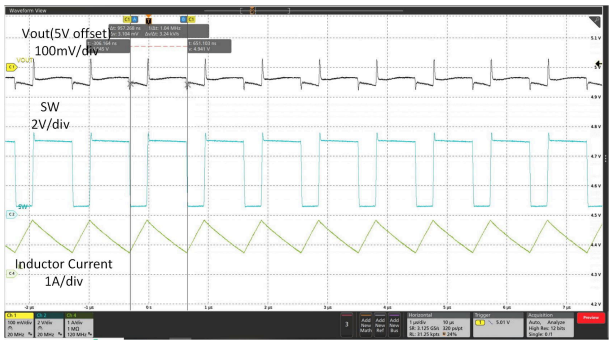
phase_align_a0 = 0h, phase_align_a1 = 0h, phase_align_a2 = 0h, PWM = 127

Figure 8-3. PWM Alignment Disabled



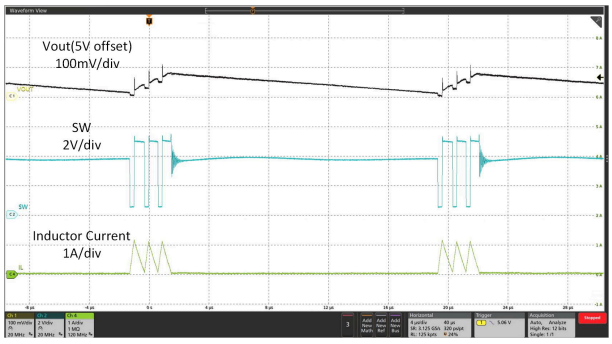
phase_align_a0 = 1h, phase_align_a1 = 2h, phase_align_a2 = 3h, PWM = 127

Figure 8-4. PWM Alignment Enabled



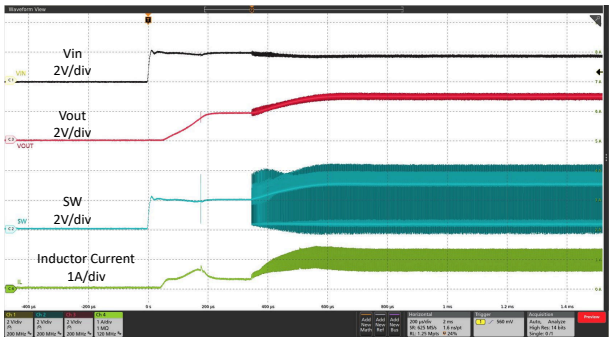
V_{IN} = 3.6V, V_{OUT} = 5V, I_{OUT} = 1A

Figure 8-5. Switching Waveform at Heavy Load



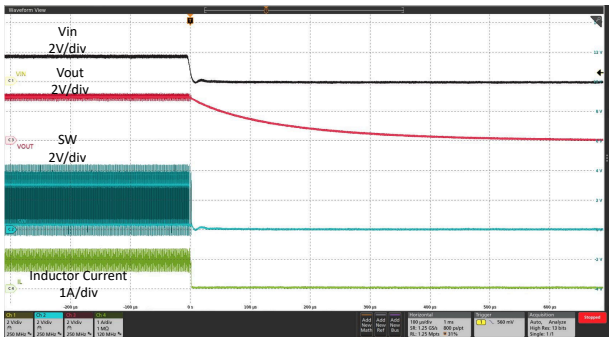
V_{IN} = 3.6V, V_{OUT} = 5V, I_{OUT} = 50mA

Figure 8-6. Switching Waveform at Light Load



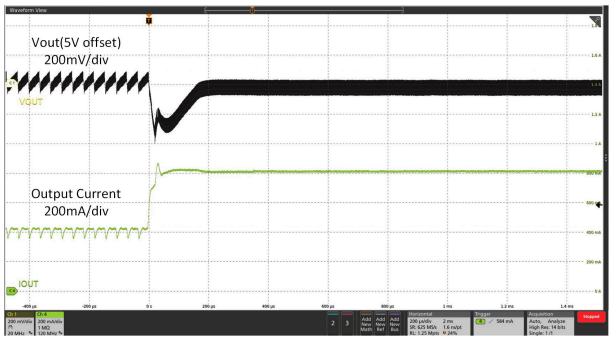
V_{IN} = 2.0V, V_{OUT} = 3.3V, 6.6Ω resistance load

Figure 8-7. Start-up Waveform



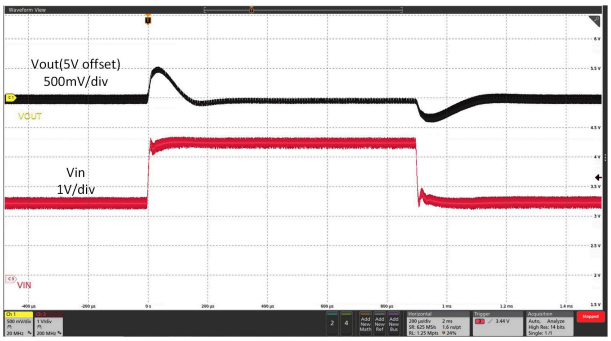
V_{IN} = 2.0V, V_{OUT} = 3.3V, 6.6Ω resistance load

Figure 8-8. Shutdown Waveform



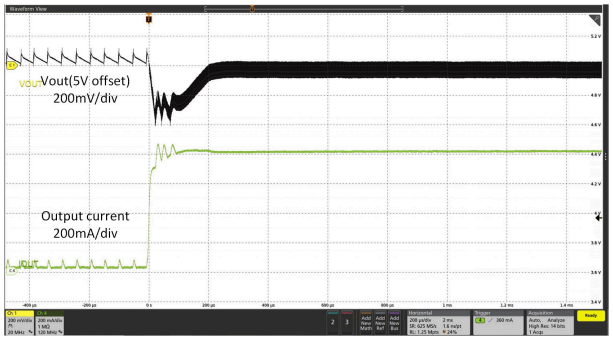
V_{IN} = 3.6V, V_{OUT} = 5V, I_{OUT} = 400mA to 800mA with 20µs slew rate

Figure 8-9. Load Transient



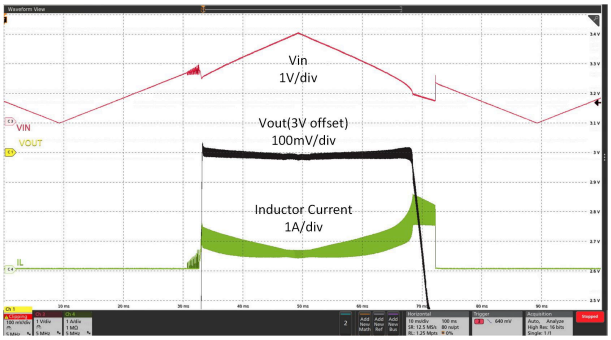
V_{IN} = 2.5V to 4.6V with 20µs slew rate, V_{OUT} = 5V
I_{OUT} = 800mA

Figure 8-10. Line Transient



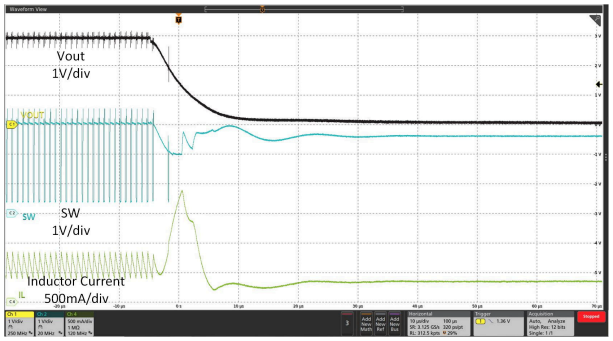
V_{IN} = 3.6V, V_{OUT} = 5V, I_{OUT} = 0A to 800mA Sweep

Figure 8-11. Load Sweep



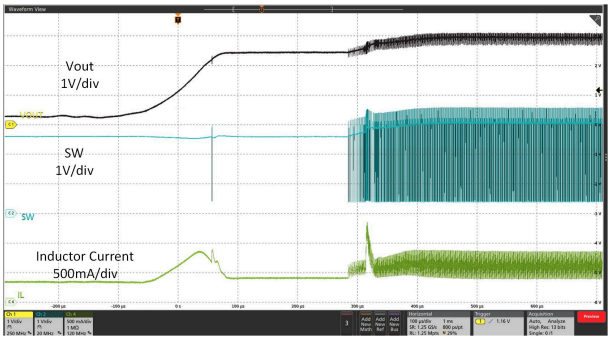
V_{IN} = 0V to 3V Sweep, V_{OUT} = 3V, 6.6Ω resistance load

Figure 8-12. Line Sweep



V_{IN} = 2.5V, V_{OUT} = 3V, 6.6Ω resistance load

Figure 8-13. Output Short Protection (Entry)



V_{IN} = 2.5V, V_{OUT} = 3V, 6.6Ω resistance load

Figure 8-14. Output Short Protection (Recover)

8.3 Power Supply Recommendations

The device is designed to operate from an input voltage supply range from 0.5V to 5.5V, with minimum 1.8V start up input voltage. This input supply must be well regulated. If the input supply is located more than a few inches from the converter, additional bulk capacitance is required near to the ceramic bypass capacitors. A typical choice is a tantalum or aluminum electrolytic capacitor with a value of 100µF.

8.4 Layout

8.4.1 Layout Guidelines

As for all switching power supplies, especially those running at high switching frequency and high currents, layout is an important design step. If the layout is not carefully done, the regulator could suffer from instability and noise problems. To maximize efficiency, switch rise and fall time are very fast. To prevent radiation of high

frequency noise (for example, EMI), proper layout of the high-frequency switching path is essential. Minimize the length and area of all traces connected to the SW pin, and always use a ground plane under the switching regulator to minimize interplane coupling. The input capacitor needs not only to be close to the VIN pin, but also to the GND pin in order to reduce input supply ripple. The most critical current path for all boost converters is from the switching FET, through the rectifier FET, then the output capacitors, and back to ground of the switching FET. This high current path contains nanosecond rise and fall time and must be kept as short as possible. Therefore, the output capacitor not only must be close to the VOUT pin, but also to the GND pin to reduce the overshoot at the SW pin and VOUT pin. For OUTx (x = 0, 1, 2, 3), low inductive and resistive path of switch load loop can help to provide a high slew rate. Therefore, path of adjecent outputs must be short and wide and avoid parallel wiring and narrow trace. For better thermal performance, TI suggest to make copper polygon connected with each pin bigger.

8.4.2 Layout Example

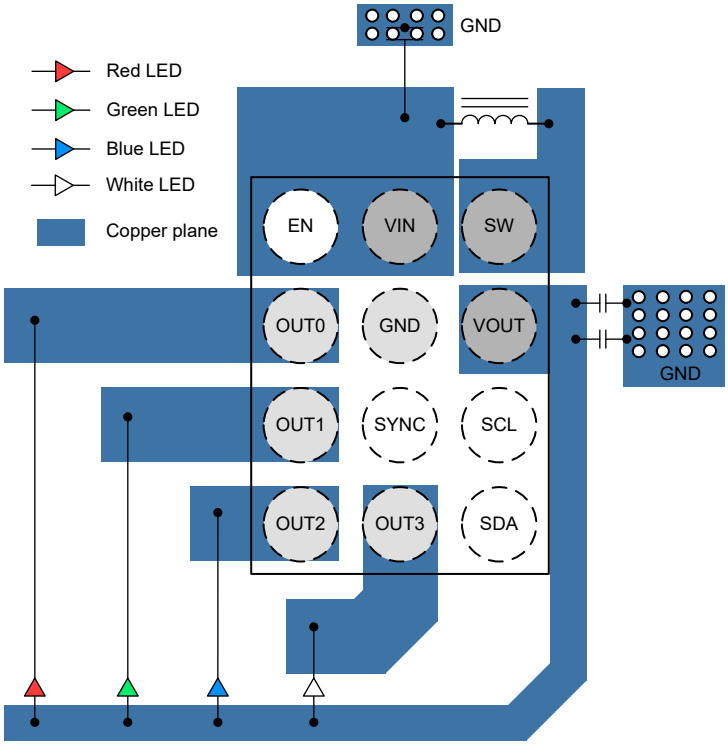


Figure 8-15. LP5811 DSBGA Package Layout Example

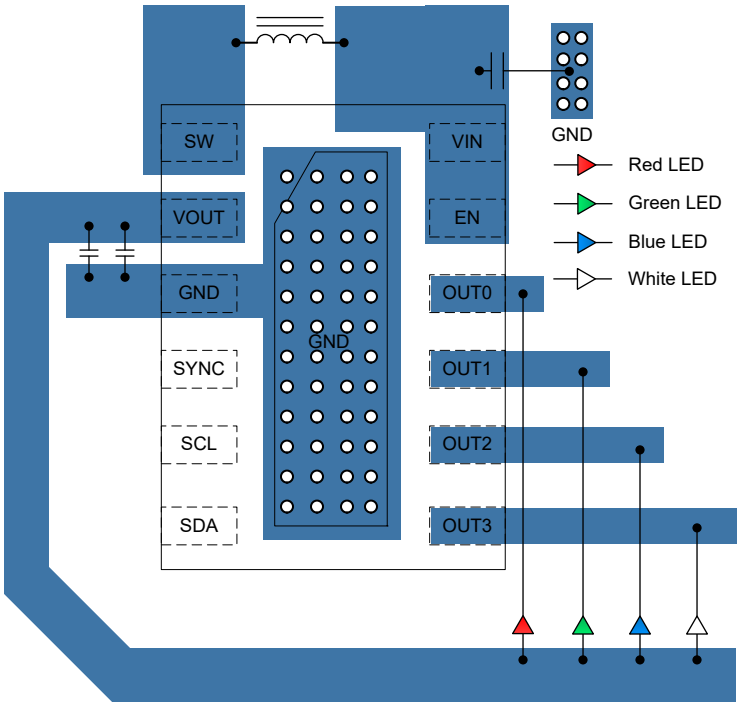


Figure 8-16. LP5811 WSON Package Layout Example

9 Device and Documentation Support

TI offers an extensive line of development tools. Tools and software to evaluate the performance of the device, generate code, and develop solutions are listed below.

9.1 Documentation Support

9.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on *Notifications* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

9.3 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

9.4 Trademarks

TI E2E™ is a trademark of Texas Instruments.
All trademarks are the property of their respective owners.

9.5 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

9.6 Glossary

TI Glossary	This glossary lists and explains terms, acronyms, and definitions.

10 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision B (December 2024) to Revision C (February 2025)	Page
• Added URL to Sample Code	29

Changes from Revision A (September 2024) to Revision B (December 2024)	Page
• Added Pin Configuration Section	4
• Updated Functional Modes image	21
• Updated parameters in Design Parameters table	27
• Removed Recommended Inductors table	27
• Changed Program Procedure	29
• Changed Program Example	29
• Removed Scan Lines and Current Sinks Waveforms of OUT0, OUT1, OUT2, OUT3, removed Scan Lines Switching Waveforms of OUT0, OUT1, OUT2, OUT3	31
• Added WSON Package Layout Example	33

Changes from Revision * (October 2023) to Revision A (September 2024)	Page
• Added WCSP package	1
• Updated Electrical Specifications Table	6
• Added DRR (WSON) Thermal Information	6
• Updated Electrical Specifications Table	6
• Added Programming Example	29

11 Mechanical, Packaging, and Orderable Information

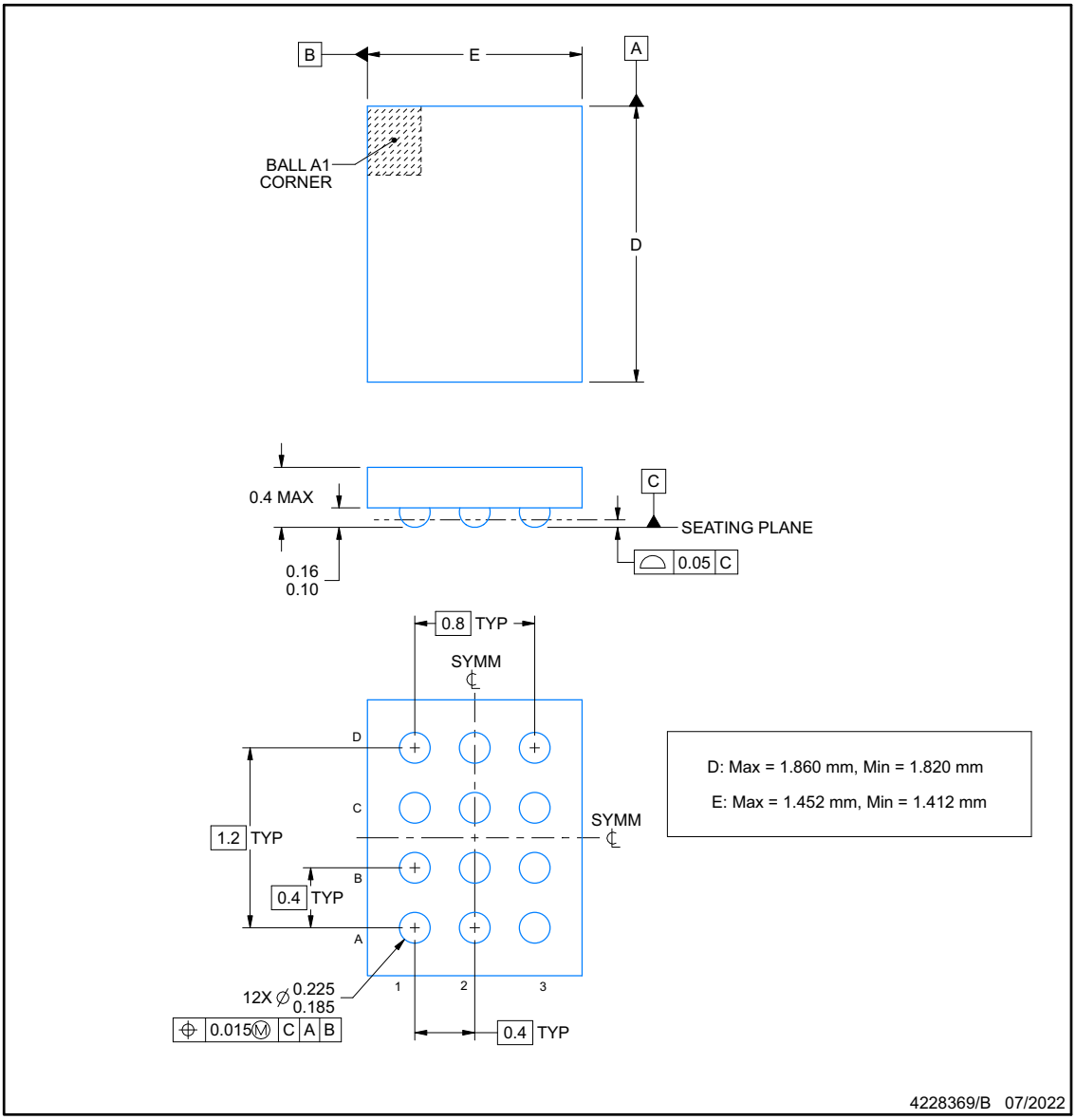
The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGE OUTLINE

YBH0012-C01

DSBGA - 0.4 mm max height

DIE SIZE BALL GRID ARRAY



NOTES:

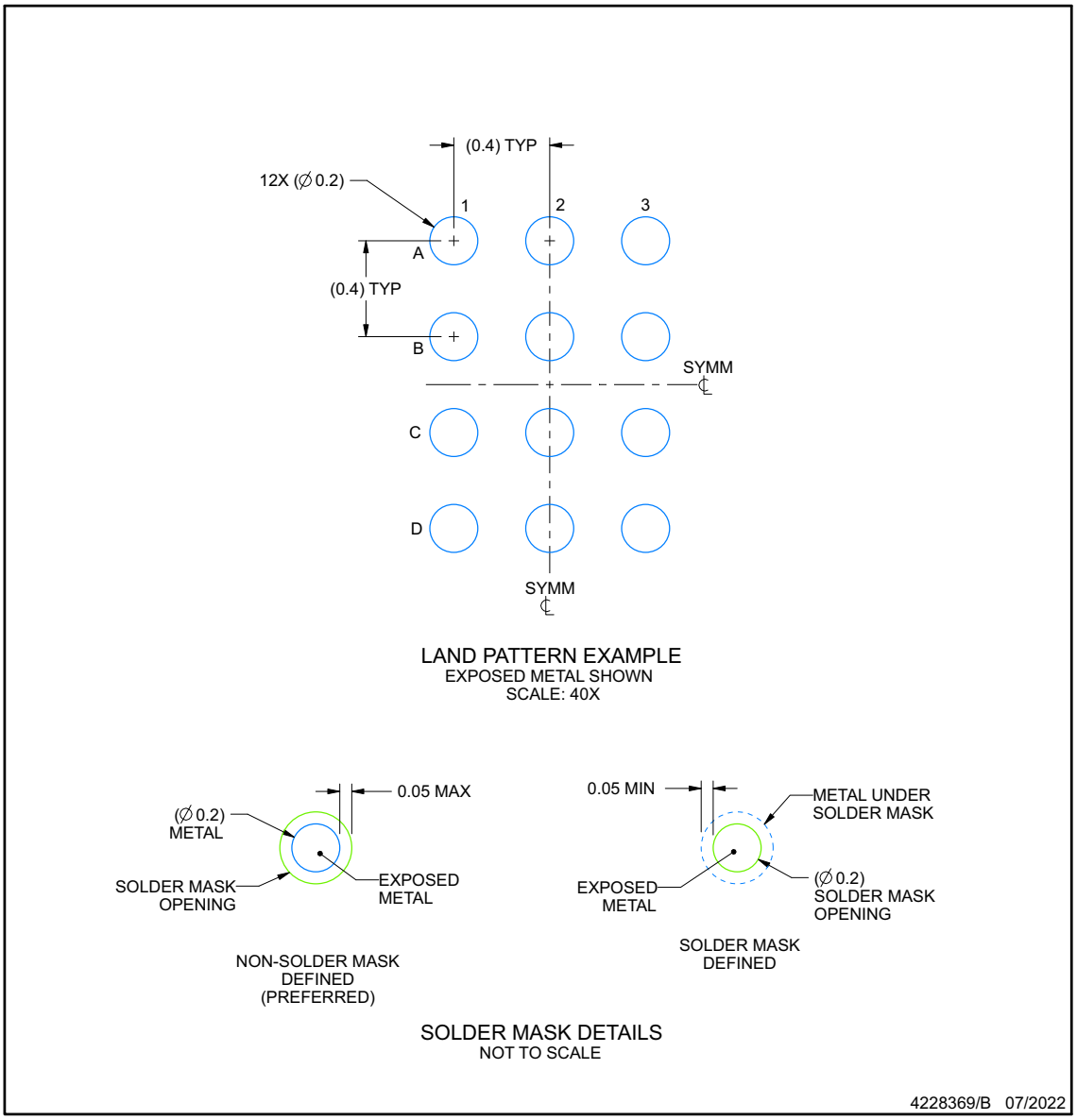
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.

EXAMPLE BOARD LAYOUT

YBH0012-C01

DSBGA - 0.4 mm max height

DIE SIZE BALL GRID ARRAY



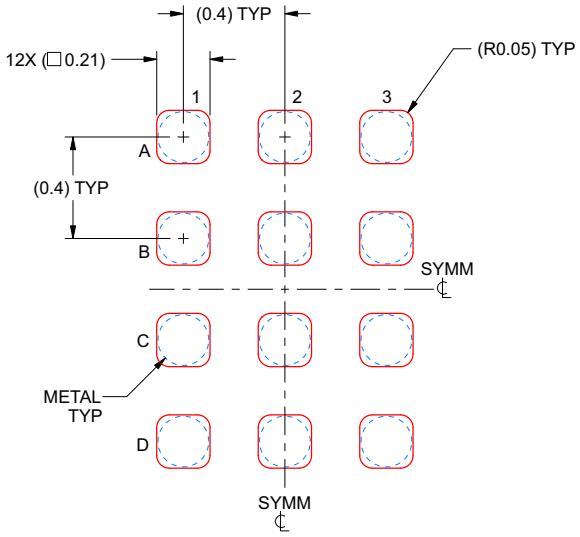
NOTES: (continued)

3. Final dimensions may vary due to manufacturing tolerance considerations and also routing constraints.
   See Texas Instruments Literature No. SNVA009 (www.ti.com/lit/snva009).

EXAMPLE STENCIL DESIGN

YBH0012-C01 — **DSBGA - 0.4 mm max height**

DIE SIZE BALL GRID ARRAY



SOLDER PASTE EXAMPLE
BASED ON 0.075 mm THICK STENCIL
SCALE: 40X

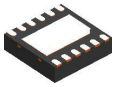
4228369/B 07/2022

NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release.

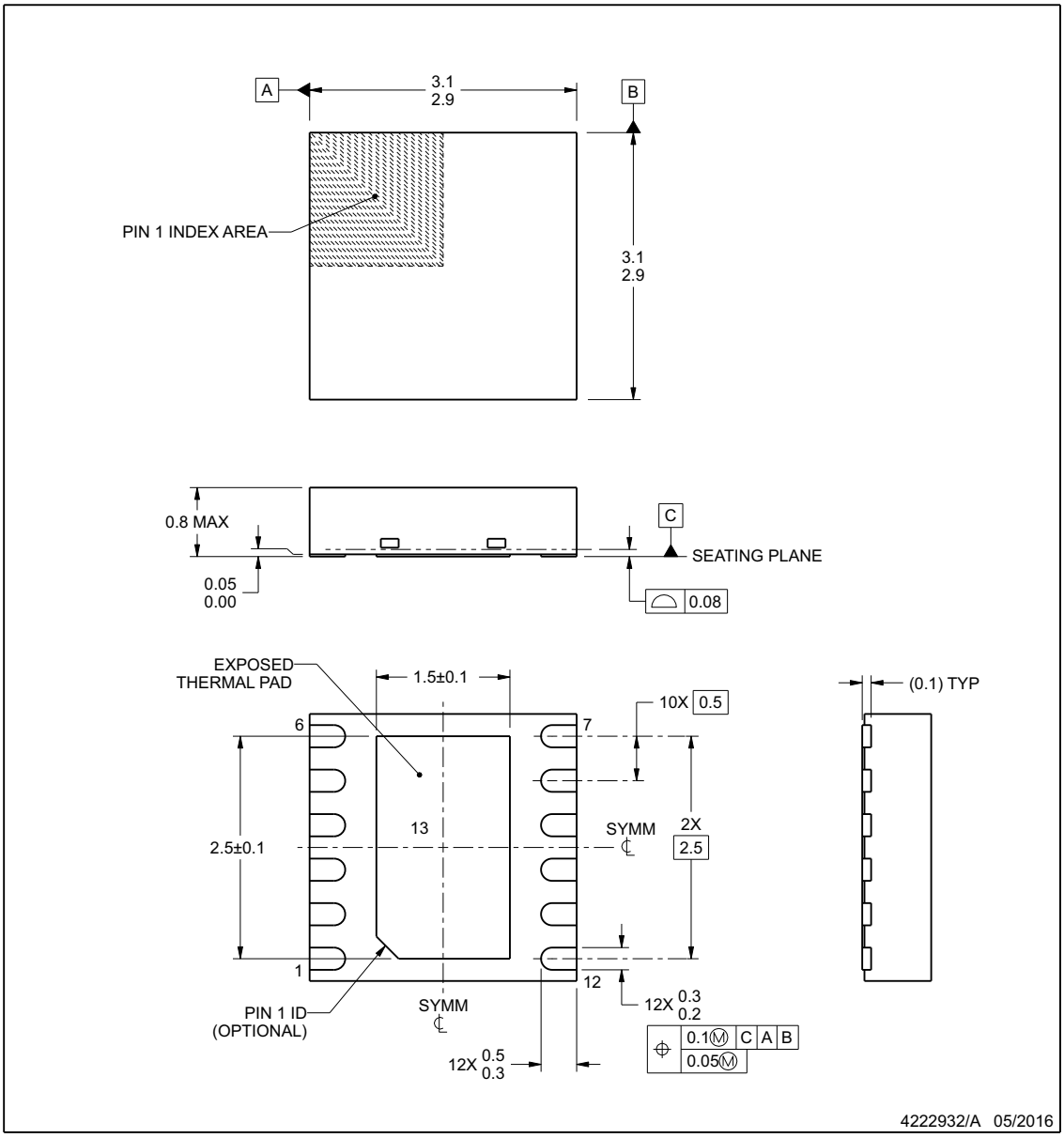
PACKAGE OUTLINE

DRR0012C



WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



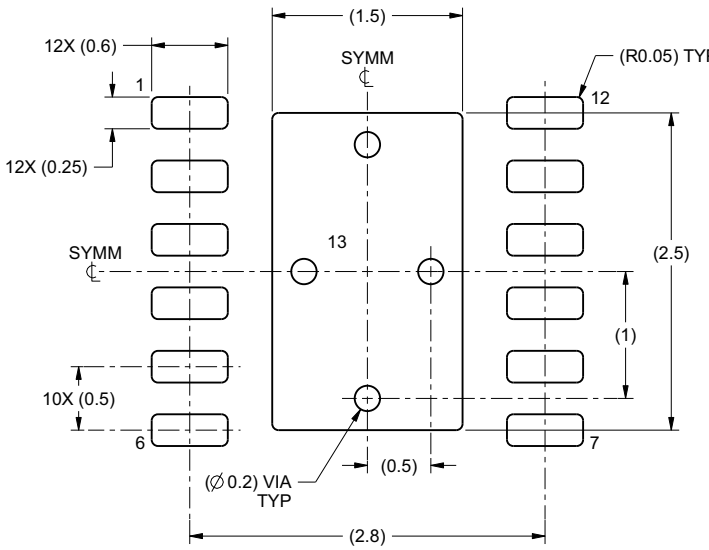
NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

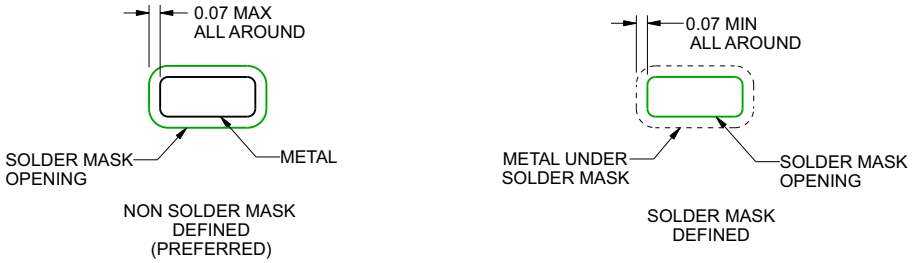
EXAMPLE BOARD LAYOUT

DRR0012C — **WSON - 0.8 mm max height**

PLASTIC SMALL OUTLINE - NO LEAD



LAND PATTERN EXAMPLE
SCALE:20X



SOLDER MASK DETAILS

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NOTES: (continued)

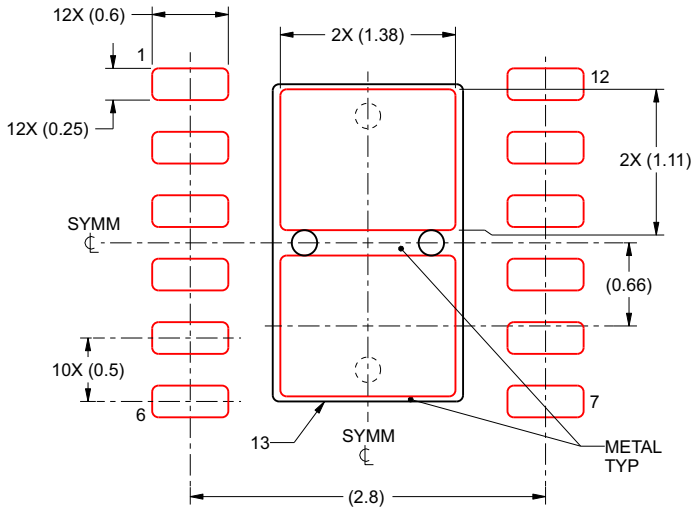
4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

EXAMPLE STENCIL DESIGN

DRR0012C

WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 13
81.7% PRINTED SOLDER COVERAGE BY AREA
SCALE:20X

4222932/A 05/2016

NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
LP5811ADRRR	Active	Production	WSON (DRR) | 12	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	5811A
LP5811AYBHR	Active	Production	DSBGA (YBH) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 85	5811A
LP5811BDRRR	Active	Production	WSON (DRR) | 12	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	5811B
LP5811BYBHR	Active	Production	DSBGA (YBH) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 85	5811B
LP5811CDRRR	Active	Production	WSON (DRR) | 12	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	5811C
LP5811CYBHR	Active	Production	DSBGA (YBH) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 85	5811C
LP5811DDRRR	Active	Production	WSON (DRR) | 12	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	5811D
LP5811DYBHR	Active	Production	DSBGA (YBH) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 85	5811D
LP5813ADRRR	Active	Production	WSON (DRR) | 12	3000 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	5813A

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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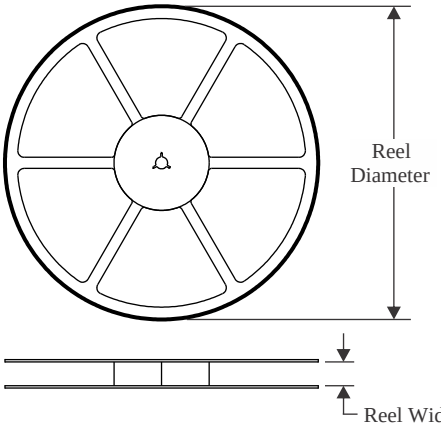
TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

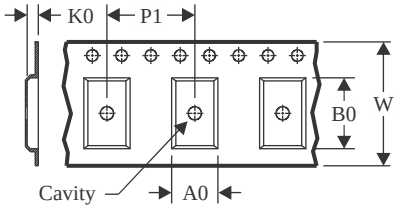
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

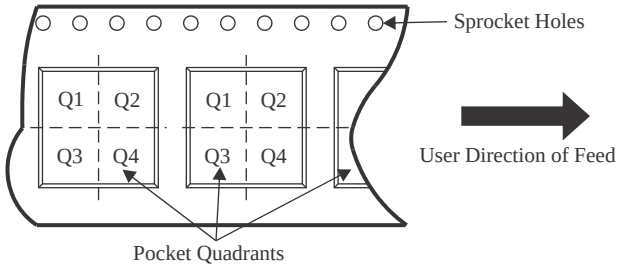


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

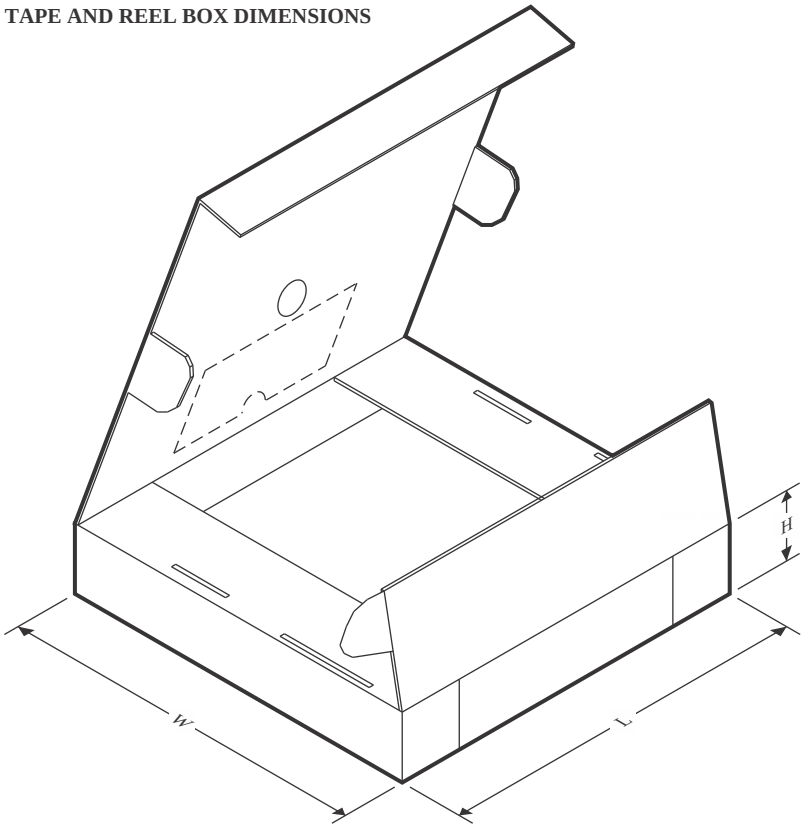
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LP5811ADRRR	WSON	DRR	12	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LP5811AYBHR	DSBGA	YBH	12	3000	180.0	8.4	1.54	2.0	0.54	4.0	8.0	Q1
LP5811BDRRR	WSON	DRR	12	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LP5811BYBHR	DSBGA	YBH	12	3000	180.0	8.4	1.54	2.0	0.54	4.0	8.0	Q1
LP5811CDRRR	WSON	DRR	12	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LP5811CYBHR	DSBGA	YBH	12	3000	180.0	8.4	1.54	2.0	0.54	4.0	8.0	Q1
LP5811DDRRR	WSON	DRR	12	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LP5811DYBHR	DSBGA	YBH	12	3000	180.0	8.4	1.54	2.0	0.54	4.0	8.0	Q1
LP5813ADRRR	WSON	DRR	12	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LP5811ADRRR	WSON	DRR	12	3000	367.0	367.0	35.0
LP5811AYBHR	DSBGA	YBH	12	3000	182.0	182.0	20.0
LP5811BDRRR	WSON	DRR	12	3000	367.0	367.0	35.0
LP5811BYBHR	DSBGA	YBH	12	3000	182.0	182.0	20.0
LP5811CDRRR	WSON	DRR	12	3000	367.0	367.0	35.0
LP5811CYBHR	DSBGA	YBH	12	3000	182.0	182.0	20.0
LP5811DDRRR	WSON	DRR	12	3000	367.0	367.0	35.0
LP5811DYBHR	DSBGA	YBH	12	3000	182.0	182.0	20.0
LP5813ADRRR	WSON	DRR	12	3000	367.0	367.0	35.0

GENERIC PACKAGE VIEW

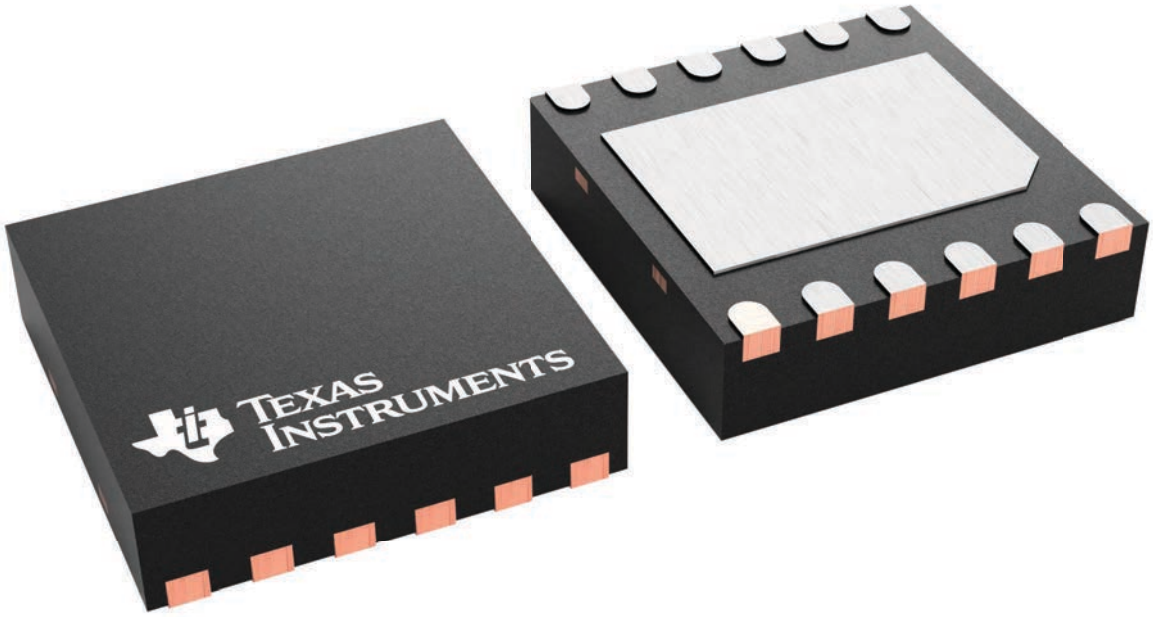
DRR 12

WSON - 0.8 mm max height

3 x 3, 0.5 mm pitch

PLASTIC SMALL OUTLINE - NO LEAD

This image is a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.



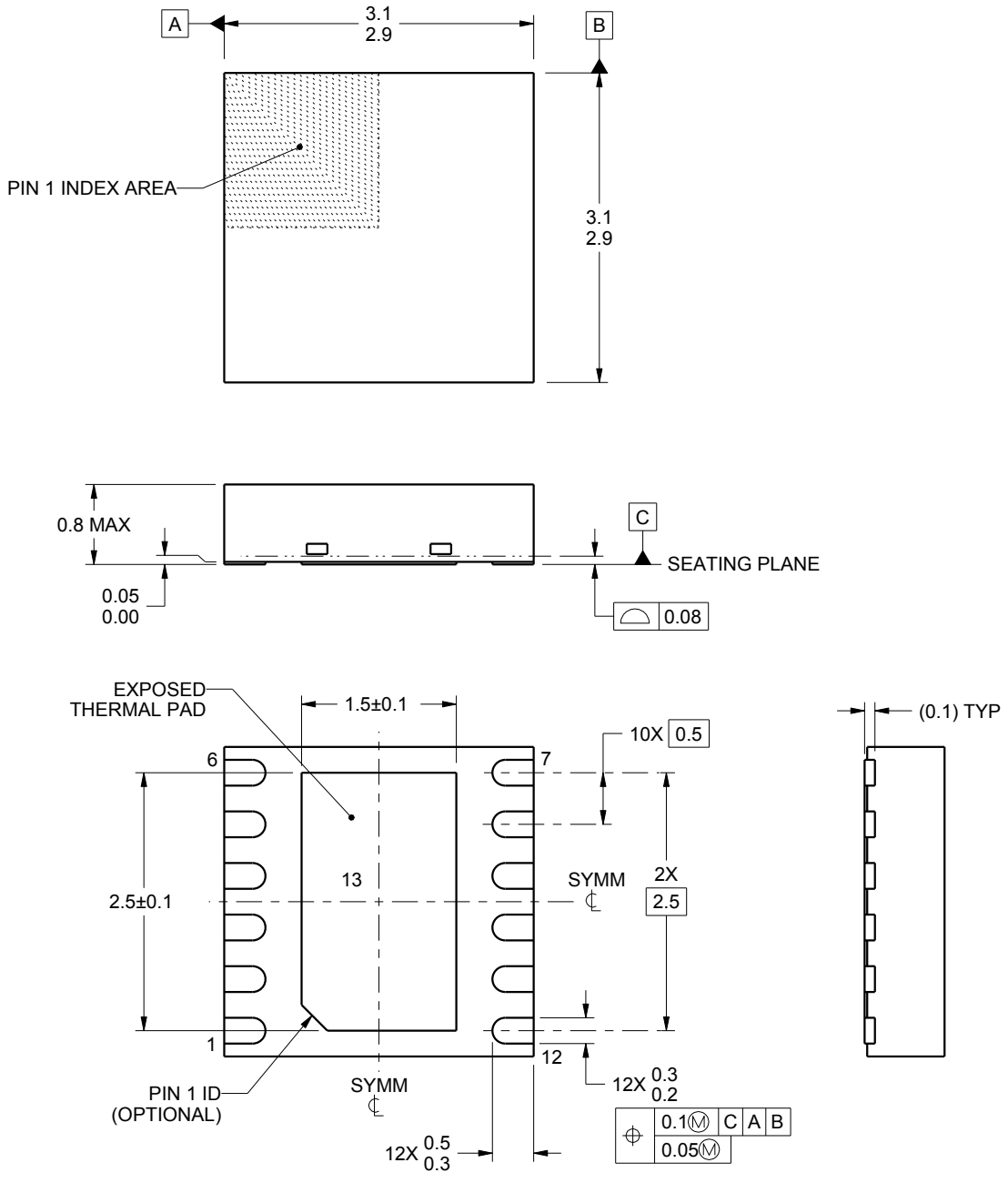
4223490/B

PACKAGE OUTLINE

DRR0012C

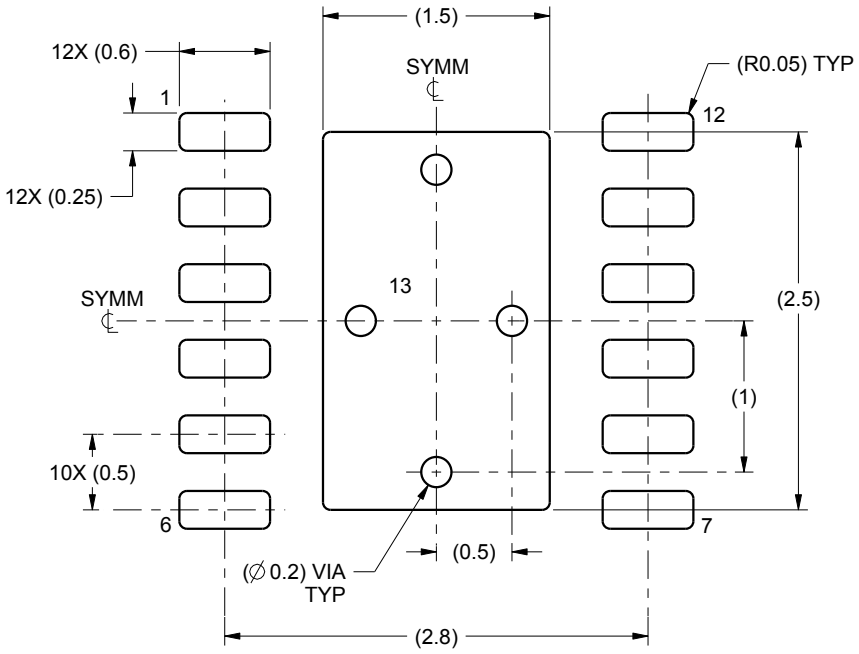
WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD

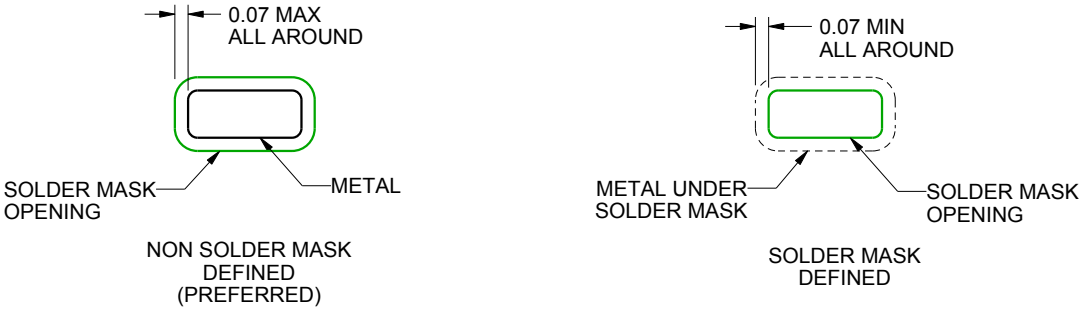


NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.



LAND PATTERN EXAMPLE
SCALE:20X



SOLDER MASK DETAILS

4222932/A 05/2016

NOTES: (continued)

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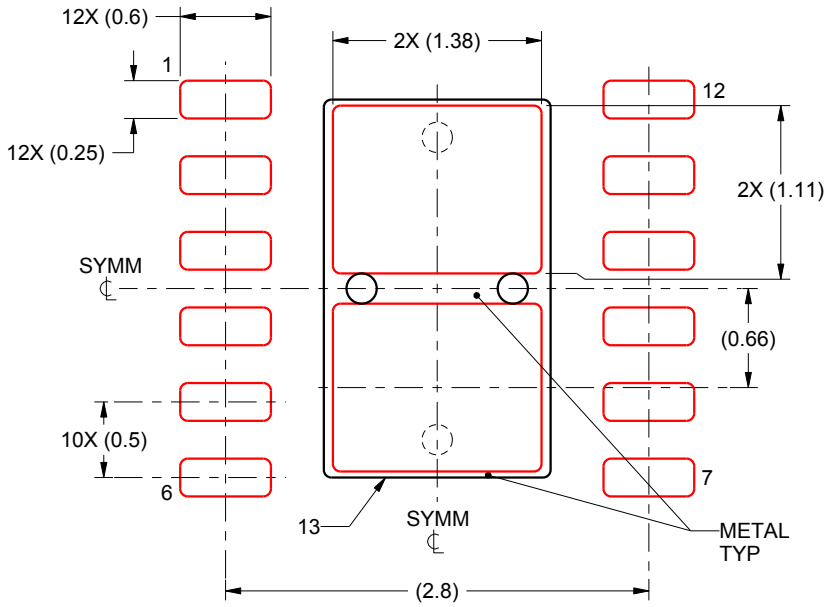
EXAMPLE STENCIL DESIGN

DRR0012C

WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 13
81.7% PRINTED SOLDER COVERAGE BY AREA
SCALE:20X

4222932/A 05/2016

NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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