

## MAX25561

## 6 x 220mA, ASIL B LED Backlight Driver with Boost Controller

### General Description

The MAX25561 is a 6-channel LED backlight driver with an integrated current-mode boost controller that operates over a switching frequency range of 400kHz to 2.2MHz and incorporates spread spectrum. Selectable phase-shifting of the output channels is included to reduce EMI. The MAX25561 provides up to 220mA per channel. The device is capable of operating down to very low battery voltages by virtue of a unique input voltage switching scheme.

Extensive diagnostics and an I<sup>2</sup>C interface are included to assist with system ASIL B compliance.

The MAX25561 is available in a compact TQFN package and operates over the -40°C to +125°C temperature range.

### Applications

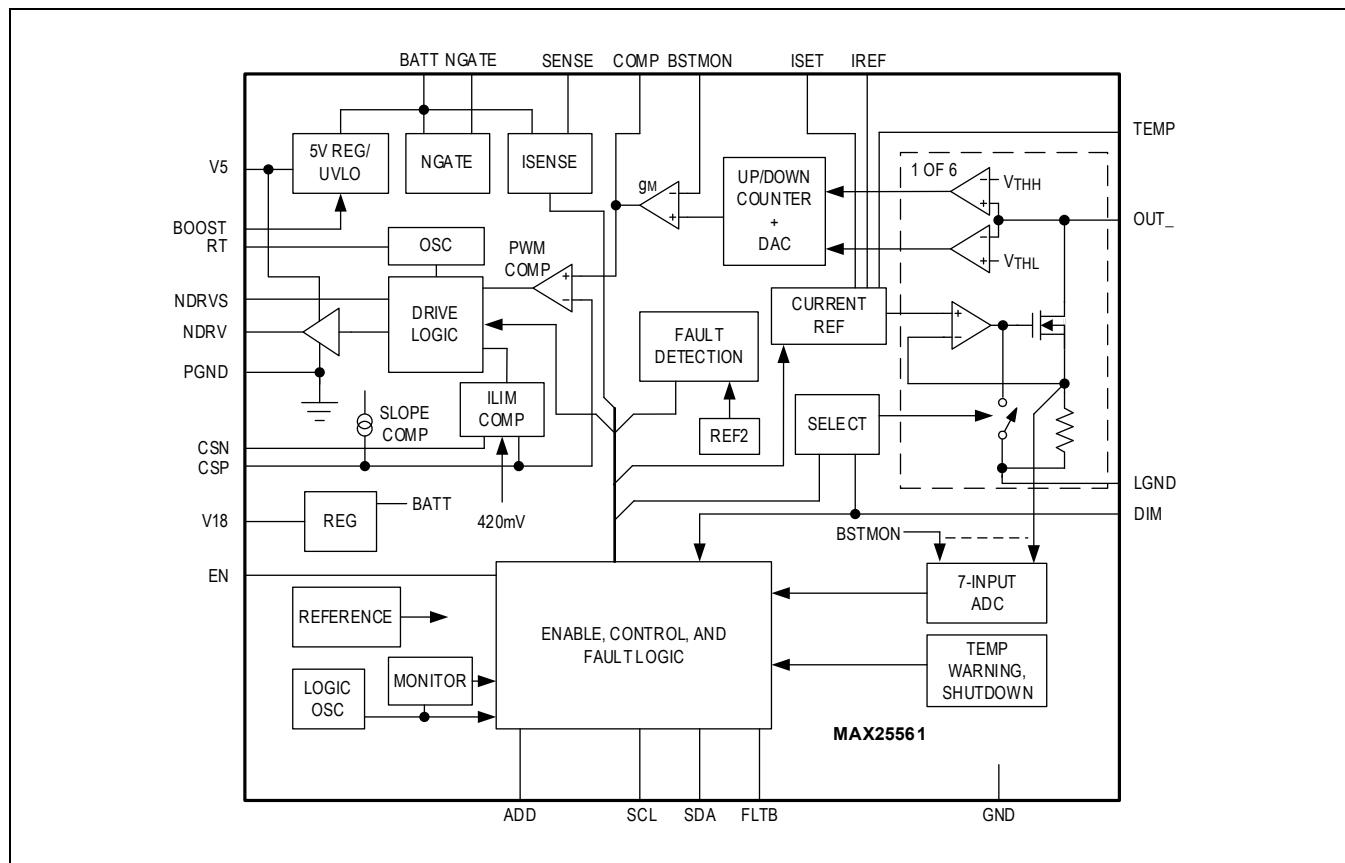
- Automotive Instrument Clusters
- Automotive Central Information Displays
- Automotive Head-Up Displays

### Benefits and Features

- Operates down to 3V on Battery Input while Maintaining 5V Gate Drive
  - Wide Boost Duty-Cycle Range
- Boost or SEPIC Current-Mode DC-DC Controller
  - 400kHz to 2.2MHz Operating Frequency Range
  - Optional Spread Spectrum
  - Can Be Synchronized to an External Clock
- LED Current Sinks
  - Up to 220mA Output Current per String
  - Low OUT\_ Regulation Voltage
  - Optional Phase-Shifting Between Channels
- 16667:1 Dimming Ratio at 200Hz
- External or Internal (I<sup>2</sup>C) Dimming
- >16667:1 Dimming Ratio with Hybrid Dimming
- Integrated Charge Pump to Drive Series nMOSFET
- Temperature Foldback Using External NTC Temperature Sensor
- Fast-Startup Option without I<sup>2</sup>C Intervention Using EN Pin Only
- FLTB Output Provides Diagnostic Information
  - Shorted or Open LEDs
  - Any OUT\_ Pin Shorted to GND
  - IREF/RT Resistor Out of Range
  - Thermal Warning/Shutdown
  - Undervoltage/Oversupply on Boost Output
  - Bandgap out-of-Range/Internal Oscillator Failure
  - V18 Internal Supply out-of-Range
  - Input Overcurrent (Measured at Boost Input Using External Sense Resistor)
  - Input/Output PWM Comparison
  - Continuous Output Current Measurement and Current Mismatch (Shutdown/Flag)
- I<sup>2</sup>C Interface with CRC
  - Readback of Measured DIM Pin Duty Cycle and Frequency
- Compact TQFN Package

[Ordering Information](#) appears at end of data sheet.

## Simplified Block Diagram



## Absolute Maximum Ratings

BATT, BOOST, OUT1-6, BSTMON, EN to GND	-0.3V to +42V
SENSE to BATT	0.3V
FLTB, DIM, SDA, SCL to GND	-0.3V to +6V
PGND to GND	-0.3V to +0.3V
LGND1, 2 to GND	-0.3V to +0.3V
NGATE to GND	-0.3V to +42V
NGATE to BATT	6V
V18 to GND	-0.3V to +2.2V
TEMP, CSP, COMP, IREF, ISET, RT, ADD to GND	-0.3V to V18 + 0.3V
V5 to GND	-0.3V to +6V
NDRV, NDRVS to GND	-0.3V to V5 + 0.3V

NDRV Peak Current (<100ns)	3A
NDRV Continuous Current	100mA
OUT_ Continuous Current	250mA
Continuous Power Dissipation (Single Layer Board) (T <sub>A</sub> = +70°C, derate 21.28mW/°C above +70°C)	1702mW
Continuous Power Dissipation (Multilayer Board) (T <sub>A</sub> = +70°C, derate 27.8mW/°C above +70°C)	2222mW
Operating Temperature Range	-40°C to +125°C
Junction Temperature Range	-40°C to +150°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (soldering, 10s)	+300°C

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

## Package Information

Package Code	T3255+6C
Outline Number	<a href="#">21-0140</a>
Land Pattern Number	<a href="#">90-0603</a>
<b>Thermal Resistance, Four-Layer Board:</b>	
Junction to Ambient ( $\theta_{JA}$ )	36°C/W
Junction to Case ( $\theta_{JC}$ )	3°C/W

Package Code	T3255Y+6C
Outline Number	<a href="#">21-100041</a>
Land Pattern Number	<a href="#">90-100066</a>
<b>Thermal Resistance, Four-Layer Board:</b>	
Junction to Ambient ( $\theta_{JA}$ )	36°C/W
Junction to Case ( $\theta_{JC}$ )	3°C/W

For the latest package outline information and land patterns (footprints), go to <https://www.analog.com/en/resources/packaging-quality-symbols-footprints/package-index.html>. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to <https://www.analog.com/en/resources/technical-articles/thermal-characterization-of-ic-packages.html>.

## Electrical Characteristics

(Limits are 100% tested at  $T_A = +25^\circ\text{C}$  and  $T_A = +125^\circ\text{C}$ . Limits over the operating temperature range and relevant supply voltage range are guaranteed by design and characterization. Specifications marked "GBD" are guaranteed by design and not production tested.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>POWER SUPPLY</b>						
BATT Operating Voltage Range	$V_{BATT}$		4.5	36	36	V
BATT Operating Voltage Range after Startup		Maximum duration 100ms	3	36	36	V
BATT Quiescent Supply Current	$I_{BATT}$	No switching	2.3	3	3	mA
BATT Shutdown Supply Current			4	10	10	$\mu\text{A}$
BATT Undervoltage Lockout Rising			4.1	4.25	4.35	V
BATT Undervoltage Lockout Falling			2.77	2.9	2.95	V
BATT Threshold for Low-Voltage Operation Mode, Falling	$V_{BATT\_LVF}$		5.28	5.45	5.6	V
BATT Threshold for Low-Voltage Operation Mode, Rising	$V_{BATT\_LVR}$		5.5	5.66	5.82	V
<b>V18 REGULATOR</b>						

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PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
V18 Output Voltage	V <sub>V18_ACC</sub>	No load on V18	1.72	1.8	1.88	V
V18 Current Limit	I <sub>LIM_V18</sub>	V <sub>V18</sub> = 1V	50			mA
V18 Undervoltage Lockout	V <sub>V18_UVLO</sub>	V18 voltage rising	1.6	1.65	1.7	V
V18 Undervoltage Hysteresis	V <sub>V18_UVLO_HYS</sub>		150			mV
V18 Power-on-Reset Level		Design guidance		1.4		V
V18OOR Diagnostic Levels			-8		+8	%
<b>V5 REGULATOR</b>						
V5 Output Voltage	V <sub>V5</sub>	V <sub>BATT</sub> = 5.75V to 36V, I <sub>V5</sub> = 10mA	4.8	5	5.2	V
V5 Dropout Voltage	V <sub>V5_DRP</sub>	V <sub>BOOST</sub> = 4.9V, I <sub>V5</sub> = 5mA		0.18	0.3	V
V5 Undervoltage Lockout	V <sub>V5_UVLO_R</sub>	V5 voltage rising	3.75	3.9	4.05	V
	V <sub>V5_UVLO_F</sub>	V5 voltage falling	3.6	3.7	3.8	
V5 Short-Circuit Current Limit	I <sub>V5_SC</sub>	V5 shorted to GND	30			mA
V5 Overvoltage Threshold, Rising			5.6	5.75	5.85	V
V5 Overvoltage Threshold Hysteresis			100			mV
<b>NGATE OUTPUT/INPUT CURRENT SENSING</b>						
NGATE Output Voltage	V <sub>NGATE</sub>	Above V <sub>BATT</sub> , 3V < V <sub>BATT</sub> < 33V, I <sub>NGATE</sub> = 1 $\mu$ A	4.3	5.25	6.3	V
NGATE Source Current	I <sub>NG_SO</sub>	V <sub>NGATE</sub> = V <sub>BATT</sub>	30	50		$\mu$ A
NGATE Sink Current	I <sub>NG_SINK</sub>	V <sub>NGATE</sub> = 14V = V <sub>BATT</sub>	6	10		mA
NGATE Output Voltage at High Input Voltage	V <sub>NGATE_HV</sub>	Above V <sub>BATT</sub> , V <sub>BATT</sub> > 35.5V, I <sub>NGATE</sub> = 1 $\mu$ A	-0.2		0	V
BATT HV Comparator Threshold	V <sub>LD_THR</sub>	BATT voltage rising	33		36	V
BATT HV Comparator Hysteresis	V <sub>LD_HYS</sub>			0.7		V
NGATE Start Delay	t <sub>NG_DEL</sub>	Delay between NGATE charge-pump turning on and BSTMON rising		2	2.2	ms
BATT-SENSE Overcurrent Threshold	V <sub>BATT_SNS</sub>		190	200	210	mV
SENSE Input Bias Current	I <sub>SNS</sub>			10	16	$\mu$ A
BATT-SENSE Overcurrent Turnoff Delay	t <sub>SD_SNS</sub>			4		ms
<b>RT OSCILLATOR</b>						
Switching Frequency Range	f <sub>SW_RT</sub>	Frequency dithering disabled	400		2200	kHz
Oscillator Frequency Accuracy		I <sub>RT</sub> = 13.85 $\mu$ A (f <sub>SW</sub> = 400kHz), I <sub>RT</sub> = 76.1 $\mu$ A (f <sub>SW</sub> = 2200kHz)	-10		+10	%

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PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Boost Converter Maximum Duty Cycle, High Frequency		$f_{SW} = 1.8\text{MHz}$ to $2.2\text{MHz}$	89	92	95	%
Boost Converter Maximum Duty Cycle, Low Frequency		$f_{SW} = 400\text{kHz}$ to $500\text{kHz}$	94		98	%
Boost Minimum On-Time				60		ns
Frequency Dither, High Setting		$SSL = 1$		$\pm 6$		%
Frequency Dither, Low Setting	SS	$SSL = 1$		$\pm 4$		%
RT Output Voltage	$V_{RT}$	$R_{RT} = 65\text{k}\Omega$ or $R_{RT} = 10\text{k}\Omega$	0.875	0.9	0.925	V
Sync Threshold	$V_{RT\_SYNC}$	$V_{RT}$ rising	0.77		0.84	V
Sync Frequency Duty Cycle	$D_{SYNC}$			50		%
Sync Frequency Range			400		2200	kHz
<b>SLOPE COMPENSATION</b>						
Peak Slope Compensation Current		Current ramp added to CS	42	50	58	$\mu\text{A}$
<b>CURRENT-LIMIT COMPARATOR</b>						
CSP Threshold Voltage	$V_{CSP-CSNL}$	$bl\_ilim = 1$	275	300	325	mV
	$V_{CSP-CSN}$	$bl\_ilim = 0$	380	410	440	
CSP Threshold Voltage During Low Voltage	$V_{CSP\_LV}$	$V_{BATT} < V_{BATT\_LVF}$ , $V_{BATT}$ falling	560	600	640	mV
CSP Input Current	$I_{CSP}$	$V_{EN} = 0\text{V}$ , $V_{CSP} = 0.4\text{V}$			1	$\mu\text{A}$
<b>ERROR AMPLIFIER</b>						
OUT_Regulation High Threshold		$V_{OUT\_falling}$	0.82	0.85	0.87	V
OUT_Regulation Low Threshold		$V_{OUT\_rising}$	0.55	0.58	0.61	V
Transconductance			410	630	890	$\mu\text{S}$
COMP Sink Current		$V_{COMP} = 1\text{V}$	270	380	500	$\mu\text{A}$
COMP Source Current		$V_{COMP} = 1\text{V}$	270	380	500	$\mu\text{A}$
<b>MOSFET DRIVER</b>						
NDRV On-Resistance, High Side		$I_{NDRV} = 100\text{mA}$		1.5	3	$\Omega$
NDRV On-Resistance, Low Side		$I_{NDRV} = -100\text{mA}$		1.2	2	$\Omega$
NDRV Rise Time		$C_{NDRV} = 1\text{nF}$		8		ns
NDRV Fall Time		$C_{NDRV} = 1\text{nF}$		8		ns
NDRVS Input Logic-Low	$V_{IL\_NDRVS}$	$V_{NDRVS}$ falling		2	2.4	V
NDRVS Input Logic-High	$V_{IH\_NDRVS}$	$V_{NDRVS}$ rising	2.55	3.3		V
NDRVS Input Current	$I_{NDRVS}$	$V_{NDRVS} = 5\text{V}$	60	80		$\mu\text{A}$

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PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>LED CURRENT SINKS</b>						
IREF Output Voltage	$V_{\text{IREF}}$	$I_{\text{IREF}} = 40\text{mA}$	0.86	0.88	0.9	V
IREF Out-of-Range Threshold	$I_{\text{REFOOR}}$		11	17.6		$\text{k}\Omega$
Full-Scale OUT_ Output Current	$I_{\text{OUT225}}$	$R_{\text{IREF}} = 22\text{k}\Omega$ , 225mA setting	217	225	231	mA
	$I_{\text{OUT100}}$	$R_{\text{IREF}} = 22\text{k}\Omega$ , 100mA setting	97.5	100	103.5	
Current Regulation Between Strings	$I_{\text{OUT\_MATCH25}}$	$I_{\text{OUT}_-} = 225\text{mA}$	-2.5		+2.5	%
Current-Setting Resolution	$I_{\text{OUT\_LSB}}$			1.5		mA
OUT_ Leakage Current	$I_{\text{OUT\_LEAK1}}$	$T_{\text{ON\_MM\_DIS}} = 1$	$V_{\text{OUT}_-} = 36\text{V}$ , $\text{DIM} = 0$ , any OUT pin	1	3	$\mu\text{A}$
	$I_{\text{OUT\_LEAK25}}$	$T_{\text{ON\_MM\_DIS}} = 1$	$V_{\text{OUT}_-} = 36\text{V}$ , $\text{DIM} = 0$ , any OUT_ pin, $T_A = +25^\circ\text{C}$		1	$\mu\text{A}$
	$I_{\text{OUT\_LEAK0}}$	$T_{\text{ON\_MM\_DIS}} = 0$		75	100	
OUT_ Minimum Pulse Width	$t_{\text{OUT}_-}$			300		ns
OUT_ Minimum Negative Pulse Width				90		ns
$I_{\text{OUT\_}} \text{ Rise Time}$	$I_{\text{OUT\_TR}}$	10% to 90% $I_{\text{OUT}_-}$		150		ns
$I_{\text{OUT\_}} \text{ Fall Time}$	$I_{\text{OUT\_TF}}$	90% to 10% $I_{\text{OUT}_-}$		20		ns
<b>DIM INPUT</b>						
DIM Frequency Range			90	50000		Hz
DIM Sampling Frequency				20		MHz
<b>FAULT DETECTION</b>						
LED Short-Detection Threshold	$V_{\text{THSHRT}}$	$\text{SLDET}[1:0] = 11$	7.7	8	8.1	V
		$\text{SLDET}[1:0] = 10$	5.6	6	6.4	
		$\text{SLDET}[1:0] = 01$	2.8	3	3.2	
OUT_ Check-LED-Source Current	$I_{\text{OUT\_CKLED}}$	$V_{\text{OUT}_-} = 0.5\text{V}$	45	60	75	$\mu\text{A}$
OUT_ Short-to-GND Detection Threshold	$V_{\text{OUT\_GND}}$	$V_{\text{OUT}_-}$ falling	230	250	270	mV
OUT_ Unused-Detection High Threshold	$V_{\text{OUT\_UN}}$		0.8	0.85	0.9	V
OUT_ Open-LED-Detection Threshold	$V_{\text{OUT\_OPEN}}$		230	250	270	mV
Shorted-LED-Detection Flag Delay	$t_{\text{SHRT}}$			6.8		$\mu\text{s}$
<b>OVERVOLTAGE AND UNDERRVOLTAGE PROTECTION</b>						
BSTMON Overvoltage Threshold	$V_{\text{BSTMON\_OV}}$	$V_{\text{BSTMON}}$ rising	0.92	0.95	0.98	V
BSTMON Overvoltage Hysteresis	$V_{\text{BSTMON\_OV}} \text{ HYS}$			50		mV

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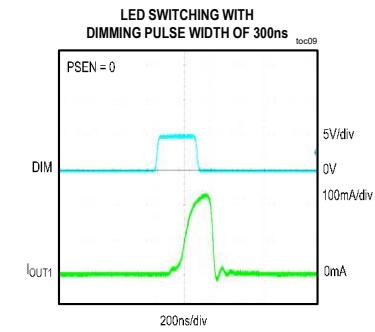
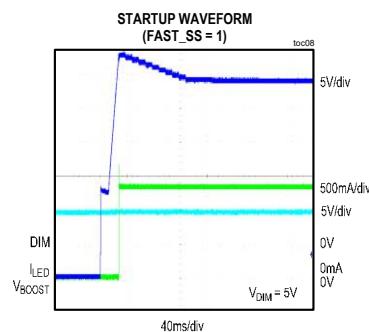
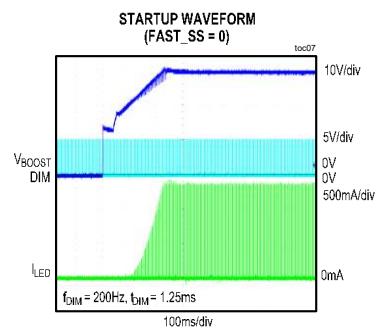
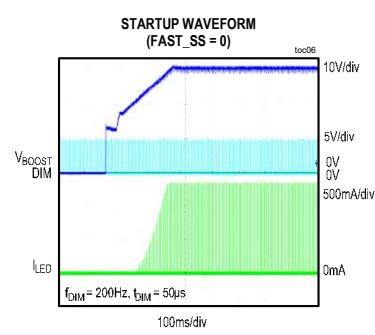
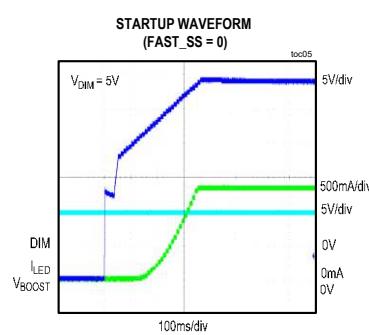
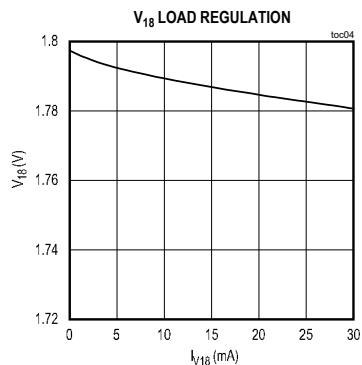
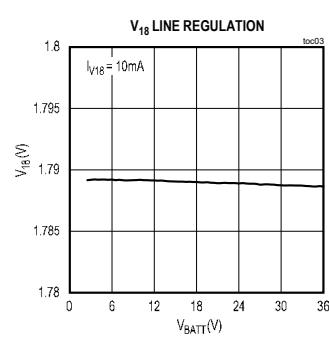
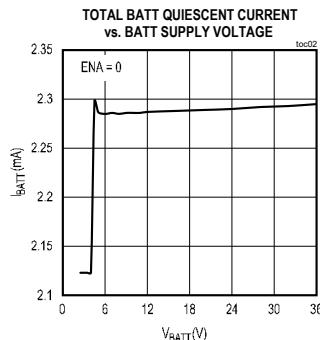
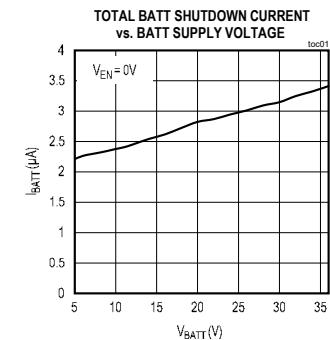
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
BSTMON Input Bias Current	$I_{\text{BSTMON}}$	$0 < V_{\text{BSTMON}} < 1\text{V}$	-1		+1	$\mu\text{A}$
BSTMON Undervoltage-Trip Threshold	$V_{\text{OVPUVLO}}$	$V_{\text{BSTMON}}$ rising	0.38	0.4	0.412	$\text{V}$
Boost Undervoltage-Detection Delay	$\text{OVPUVLO\_BL}_K$			10		$\mu\text{s}$
Boost Undervoltage-Blanking Time		After soft-startup, $\text{fast\_ss} = 0$	49	53.25	57.5	$\text{ms}$
		After soft-start, $\text{fast\_ss} = 1$	26.28	28.46	30.74	
<b>TEMP PIN</b>						
TEMP Pin Voltage	$V_{\text{TEMP}}$	$I_{\text{TEMP}} = -10\mu\text{A}$	380	400	420	$\text{mV}$
$I_{\text{TEMP}}$ to $I_{\text{OUT\_Gain}}$		$V_{\text{TEMP}} < 400\text{mV}$		0.67		$\%/\mu\text{A}$
TEMP Pin Disable Threshold				0.5		$\text{V}$
TEMP Pin Leakage Current				0.005	0.5	$\mu\text{A}$
TEMP Current for LED Current Disable	$I_{\text{TEMPD}}$			125		$\mu\text{A}$
<b>LOGIC INPUTS AND OUTPUTS (EN, SCL, SDA, DIM, FLTB)</b>						
Digital Inputs Logic-High	$V_{\text{IH}}$			1.22		$\text{V}$
Digital Inputs Logic-Low	$V_{\text{IL}}$				0.6	$\text{V}$
Digital Inputs Hysteresis	$V_{\text{HYS}}$			300		$\text{mV}$
EN Input Pull-Down Resistor	$R_{\text{PDEN}}$		100	165	240	$\text{k}\Omega$
EN Blanking Time	$t_{\text{EN\_BLK}}$			10		$\mu\text{s}$
DIM, ADD, and MODE Pull-up Current	$I_{\text{DIN\_PUP}}$	$V_{\text{DIN}} = 0\text{V}$		2		$\mu\text{A}$
DIM Frequency Range			90			$\text{Hz}$
DIM Sampling Frequency			18	20	22	$\text{MHz}$
SCL Input Current	$I_{\text{DIN}}$	$V_{\text{DIN}} = +5\text{V}$		1		$\mu\text{A}$
FLTB, SDA Output Low Voltage	$V_{\text{OL\_OUT}}$	$I_{\text{FLTB}} = I_{\text{SDA}} = 5\text{mA}$			0.4	$\text{V}$
FLTB, SDA Output Leakage Current	$I_{\text{OUT\_LEAK}}$	$V_{\text{EN}} = 0\text{V}$ , $V_{\text{FLTB}} = V_{\text{SDA}} = 5.5\text{V}$			1	$\mu\text{A}$
<b>THERMAL SHUTDOWN</b>						
Thermal-Shutdown Threshold				160		$^\circ\text{C}$
Thermal-Shutdown Hysteresis				17		$^\circ\text{C}$
Thermal Warning Threshold				125		$^\circ\text{C}$
<b>ANALOG-TO-DIGITAL CONVERTER (ADC)</b>						
ADC Measurement Resolution	ADC BIT			8		bits
Total Measurement Error, Current	$E_{\text{ADC\_I}}$	225mA setting	-12		+12	$\text{mA}$

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PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Total Measurement Error, Voltage	E_ADC_V	$V_{\text{BSTMON}} = 1\text{V}$ , $V_{\text{BATT}} - V_{\text{SENSE}} = 200\text{mV}$	-50		+50	mV
ADC Gain Error	ADC GAIN	225mA setting	-4		+4	%
ADC Offset Error	ADC OFF	225mA setting	-4		+4	LSB
Measurement Resolution, Current	LSB OUT			1		mA
Measurement Resolution, BSTMON	LSB <sub>BSTMON</sub>			3.92		mV
Measurement Resolution, BATT-SENSE	LSB <sub>SENSE</sub>			1		mV
<b>I<sup>2</sup>C INTERFACE</b>						
Clock Frequency	f <sub>SCL</sub>			0.4		MHz
Hold Time (Repeated) START	t <sub>HD:STA</sub>		600			ns
SCL Low Time	t <sub>LOW</sub>		1300			ns
SCL High Time	t <sub>HIGH</sub>		600			ns
Setup Time (Repeated) START	t <sub>SU:STA</sub>		600			ns
Data Hold Time	t <sub>HD:DAT</sub>		0			ns
Data Setup Time	t <sub>SU:DAT</sub>		100			ns
Setup Time for STOP Condition	t <sub>SU:STO</sub>		600			ns
Spike Suppression			50			ns

## Typical Operating Characteristics

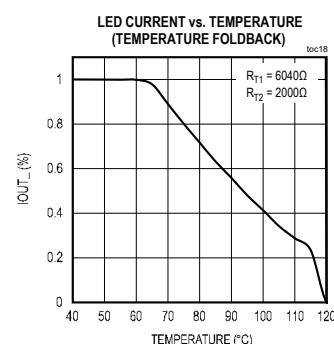
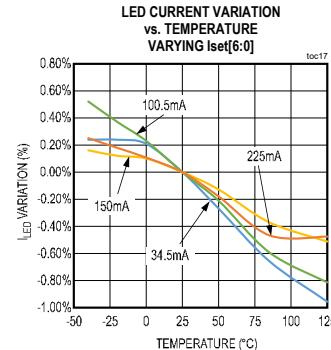
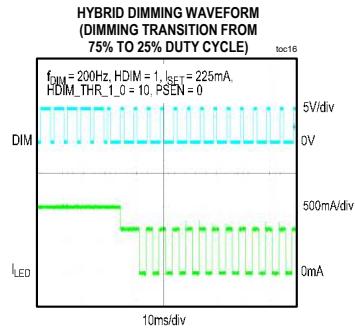
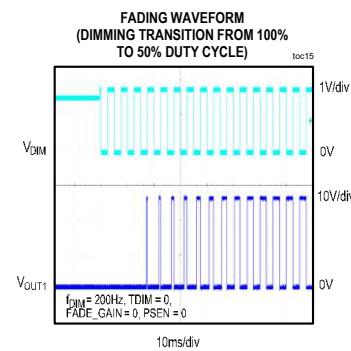
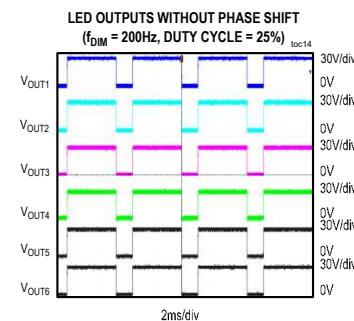
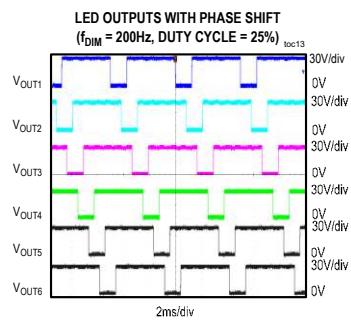
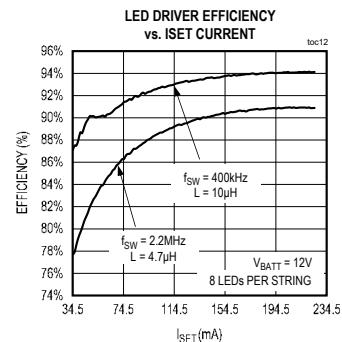
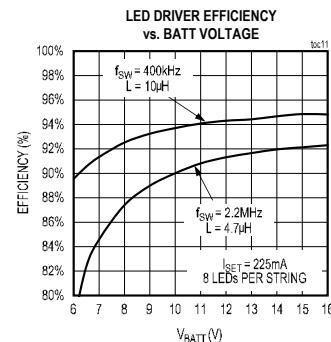
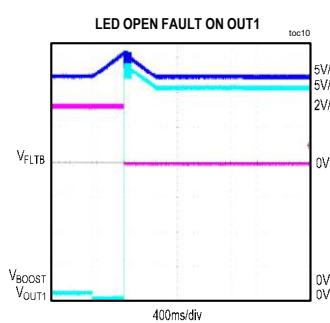
( $V_{IN} = V_{EN} = 12V$ , 6x9 LED load at 200mA,  $f_{SW} = 2.2\text{MHz}$ ,  $T_A = +25^\circ\text{C}$  unless otherwise noted.)



# 6 x 220mA, ASIL B LED Backlight Driver with Boost Controller

MAX25561

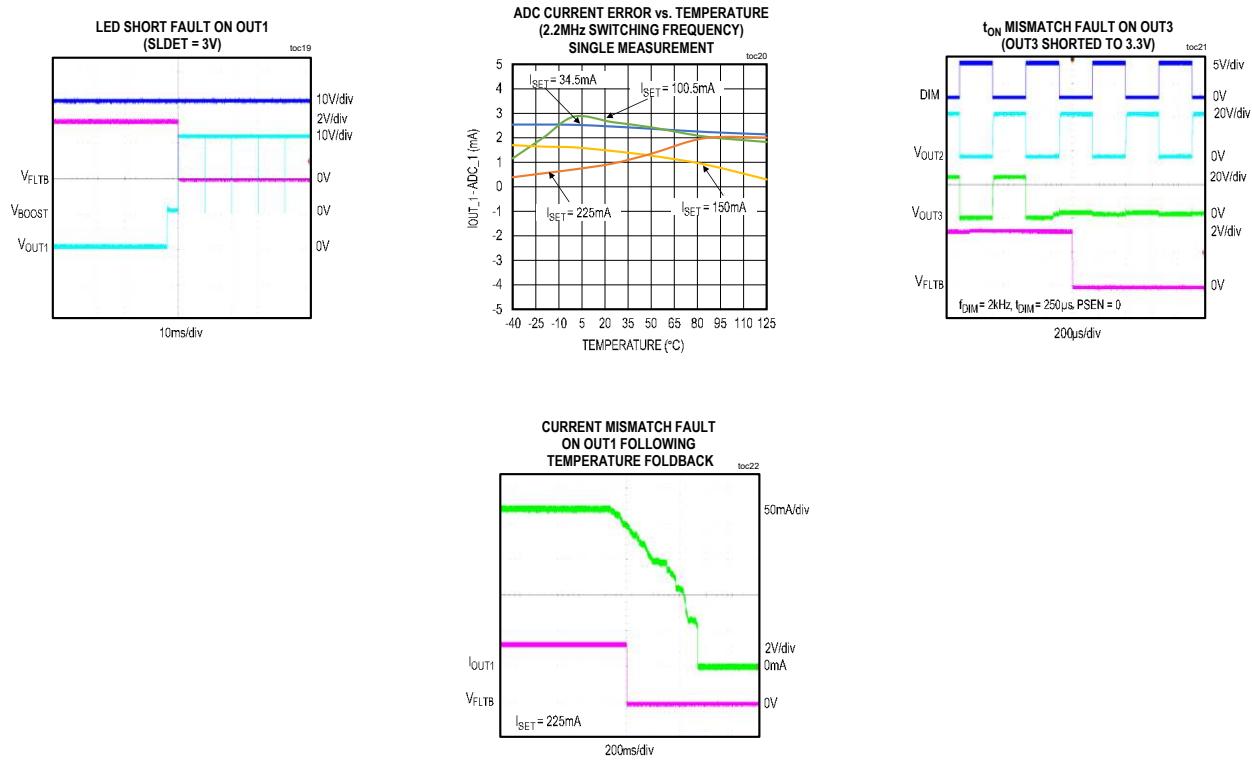
( $V_{IN} = V_{EN} = 12V$ , 6x9 LED load at 200mA,  $f_{SW} = 2.2\text{MHz}$ ,  $T_A = +25^\circ\text{C}$  unless otherwise noted.)



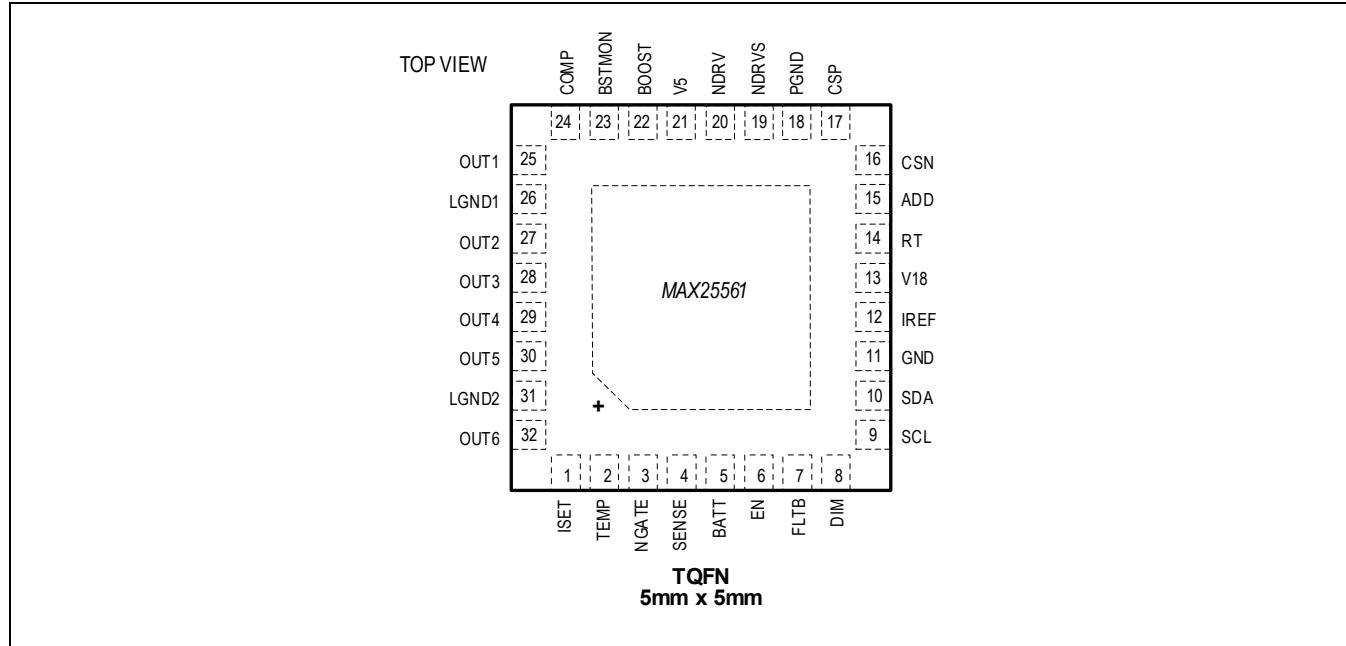
# 6 x 220mA, ASIL B LED Backlight Driver with Boost Controller

MAX25561

( $V_{IN} = V_{EN} = 12V$ , 6x9 LED load at 200mA,  $f_{SW} = 2.2\text{MHz}$ ,  $T_A = +25^\circ\text{C}$  unless otherwise noted.)



## Pin Configurations

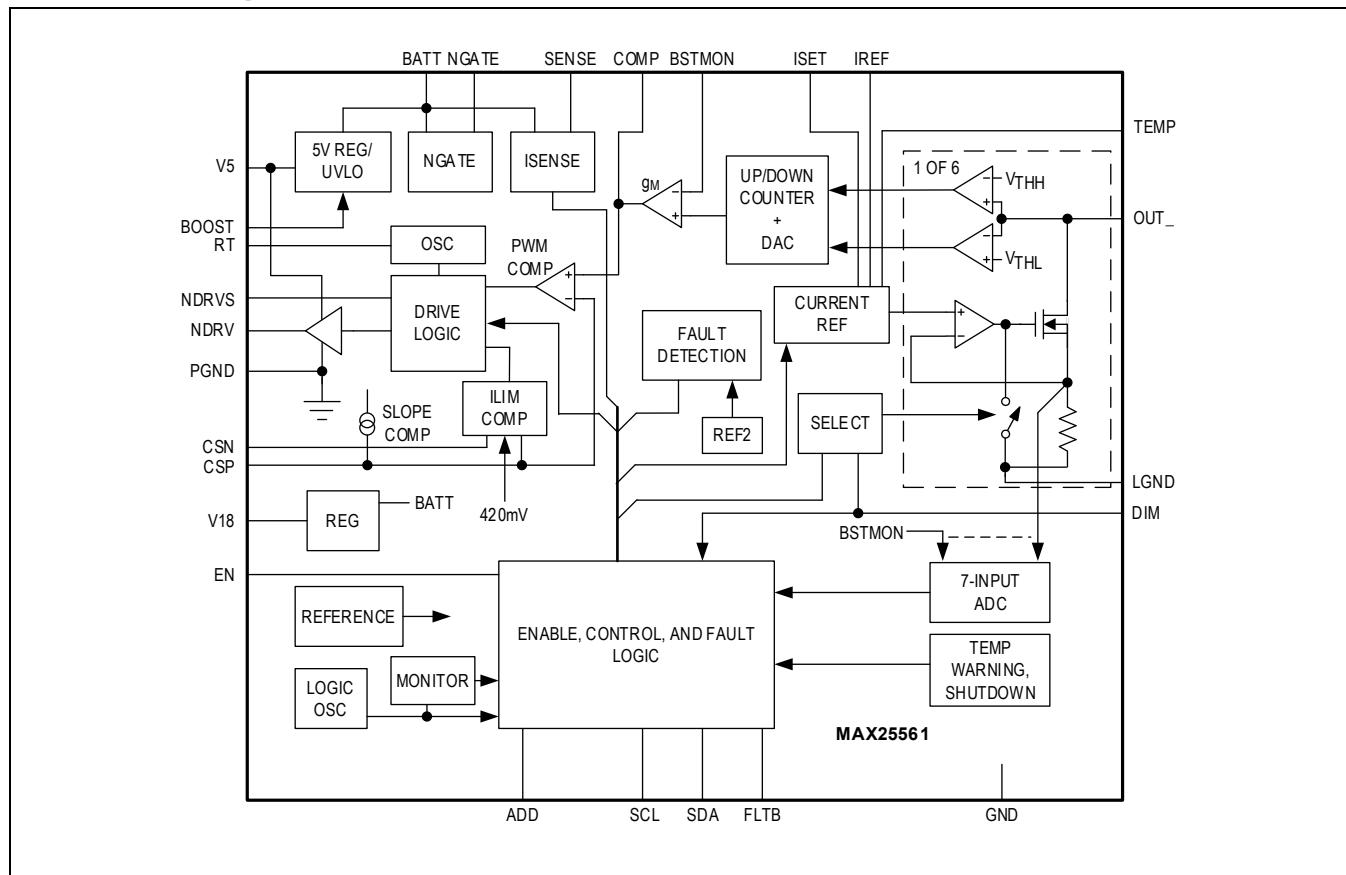


## Pin Descriptions

PIN	NAME	FUNCTION
1	ISET	Startup LED Current Setting Pin. Connect a resistor to this pin to set the initial LED current in each of the channels and enable startup when the EN pin is taken high. LED current can be adjusted by writing to the ISET_REG register after startup. If using I <sup>2</sup> C to set the LED current and enable the device, connect the ISET pin to V18.
2	TEMP	Temperature Sensor Input. To implement LED current reduction at high temperatures, connect an NTC temperature sensor to GND with resistors from the NTC to TEMP and V18. If unused, connect TEMP to V18.
3	NGATE	Gate Connection for External Series nMOSFET Driven by the Internal Charge Pump
4	SENSE	Boost Input Current-Sense Input. Connect to a sense resistor in series with the boost input. If unused, connect SENSE to BATT.
5	BATT	LED Driver Supply Input. Connect BATT to a 4.5V to 40V supply. Bypass BATT to ground with ceramic capacitors of 2.2 $\mu$ F and 0.1 $\mu$ F.
6	EN	Enable Input. When EN is high, the device is enabled. When EN is low, the device is in shutdown with low quiescent current. EN has an internal pull-down resistor.
7	FLTB	Active-Low, Open-Drain Fault Indication Output. Connect an external pull-up resistor from FLTB to an external supply lower than 5V.
8	DIM	PWM Dimming Input. DIM has an internal pull-up to V18.
9	SCL	I <sup>2</sup> C Clock Input
10	SDA	I <sup>2</sup> C Data I/O
11	GND	Ground Connection
12	IREF	Reference Current Set Pin. Connect a 1% resistor of value 22k $\Omega$ from IREF to GND.
13	V18	Output of Internal 1.8V Regulator. Connect a 2.2 $\mu$ F capacitor from V18 to GND with an additional 100nF capacitor close to the V18 and GND pins.
14	RT	Frequency Setting Resistor for Backlight Boost Converter
15	ADD	Device Address Select Pin. Connect to GND or V18 to select the device I <sup>2</sup> C address. See <a href="#">Table 3</a> . ADD has an internal pull-up to V18.
16	CSN	LED Driver MOSFET Negative Current-Sense Connection. Connect this pin directly to the GND side of the compensation network connected to the COMP pin.
17	CSP	LED Driver MOSFET Positive Current-Sense Connection. Connect a sense resistor from the MOSFET source to PGND and a further resistor from the MOSFET source to the CSP pin to set the slope compensation (see the <a href="#">Current-Sense Resistor and Slope Compensation</a> section).
18	PGND	Power Ground Connection
19	NDRV <sub>S</sub>	Sense Connection for Gate of External MOSFET. Connect NDRV <sub>S</sub> directly to the gate after the gate resistor.
20	NDRV	Switching nMOSFET Gate-Driver Output. Connect NDRV to the gate of the external switching power MOSFET. Typically, a small resistor (1 $\Omega$ to 22 $\Omega$ ) is inserted between the NDRV output and nMOSFET gate to decrease the slew rate of the gate driver and reduce the switching noise.
21	V5	5V Regulator Output, Voltage Supply for NDRV Gate Driver. Place 2.2 $\mu$ F and 22nF ceramic capacitors as close as possible to the device, between V5 and GND.
22	BOOST	Boost Output Voltage Connection. BOOST is used to supply power to the V <sub>CC</sub> regulator when the IN voltage is too low. Bypass with a 0.1 $\mu$ F capacitor placed close to the pin.
23	BSTM <sub>ON</sub>	LED Driver Output-Voltage-Sensing Input. This voltage is used for overvoltage and undervoltage protection. Connect a resistor-divider between the boost converter output, BSTM <sub>ON</sub> pin, and GND.
24	COMP	LED Driver Switching-Converter Compensation Input. Connect an RC network from COMP to GND to compensate the backlight boost converter.
25	OUT1	LED String 1 Cathode Connection. Do not connect more than 470pF of capacitance from OUT1 to GND.
26	LGND1	LED Ground Connection
27	OUT2	LED String 2 Cathode Connection. Connect OUT2 to ground using a 9.1k $\Omega$ resistor if not used. Do not connect more than 470pF of capacitance from OUT2 to GND.

28	OUT3	LED String 3 Cathode Connection. Connect OUT3 to ground using a 9.1kΩ resistor if not used. Do not connect more than 470pF of capacitance from OUT3 to GND.
29	OUT4	LED String 4 Cathode Connection. Connect OUT4 to ground using a 9.1kΩ resistor if not used. Do not connect more than 470pF of capacitance from OUT4 to GND.
30	OUT5	LED String 5 Cathode Connection. Connect OUT4 to ground using a 9.1kΩ resistor if not used. Do not connect more than 470pF of capacitance from OUT5 to GND.
31	LGND2	LED Ground Connection
32	OUT6	LED String 6 Cathode Connection. Connect OUT4 to ground using a 9.1kΩ resistor if not used. Do not connect more than 470pF of capacitance from OUT6 to GND.
—	EP	Exposed Pad. Connect to a large contiguous copper-ground plane for optimal heat dissipation. Do not use EP as the only electrical ground connection.

## Functional Diagrams



## Detailed Description

The MAX25561 is a 6-channel LED backlight driver with an integrated current-mode boost controller that operates over a switching frequency range of 400kHz to 2.2MHz and incorporates spread spectrum. Selectable phase-shifting of the output channels is included to reduce EMI. The MAX25561 provides up to 220mA per channel. The device is capable of operating down to very low battery voltages while maintaining 5V drive for the external MOSFET at NDRV.

Extensive diagnostics and an I<sup>2</sup>C interface are included to assist with system ASIL B compliance.

The MAX25561 is available in a compact TQFN package and operates over the -40°C to +125°C temperature range.

### Undervoltage Lockout

The device features three undervoltage circuits that monitor the input voltage at BATT and the outputs of the internal LDO regulators at V5 and V18. The backlight boost can be enabled only when BATT, V5, and V18 exceed their respective UVLO thresholds.

### BATT\_UV Indication Bit

The BATT\_UV bit in DIAG2\_REG indicates when the BATT input is below the undervoltage lockout. During power-up, until the BATT input has crossed its undervoltage threshold, it is not possible to communicate with the device and thus the BATT\_UV bit cannot be read.

### Low-Voltage Operation

After the boost soft-start is completed, the MAX25561 continues to operate with BATT voltages lower than 5V while maintaining 5V drive for the external MOSFET at NDRV. When the voltage at BATT drops to  $V_{BATT\_LV}$ , the V5 regulator switches its input from BATT to BOOST, the boost converter current limit is automatically increased to  $V_{CSP\_LV}$ , and the switching frequency is reduced if it is greater than 1.4MHz. Switchover occurs as long as the voltage on BOOST is above

$V_{BATT\_LVF}$ . In this mode, if the standard current limit is exceeded on four consecutive cycles, a 100ms timer is started, which returns the current limit to its original value when it expires.

When BATT returns to a voltage above  $V_{BATT\_LVR}$ , the V5 regulator resumes operation from BATT and the converter current limit and switching frequency return to their former values. Bypass BATT and BOOST with ceramic capacitors placed close to the respective pins.

At very low input voltages, the efficiency of the boost converter decreases, and the input current can reach very high levels as a consequence. The external boost converter components must be selected for worst-case operation. An alternative is to reduce the output power at low input voltages.

If the voltage at BATT drops below the undervoltage lockout level ( $V_{BATT\_UVF}$ ) at any time, the boost converter is disabled.

### Input Current Monitoring

Input overcurrent protection is implemented by using an external sense resistor connected between BATT and SENSE. If the voltage across the sense resistor exceeds 200mV after the 2ms NGATE turn-on phase (Stage 1 of startup) for a time greater than 4 $\mu$ s, the boost converter is latched off, the ISNS\_SD bit in the DIAG2\_REG register is set, and the FLTB pin is asserted low. The shutdown function can be disabled by setting the DIS\_ISNS\_SD bit to 1. In that case, the device continues operation when an input overcurrent is detected; the ISNS\_SD bit is set, but FLTB does not assert low.

To reenable the device, toggle the power supply, the EN input pin, or the ENA bit.

The value of the voltage between BATT and SENSE is continuously sampled by the internal ADC, and the most recent value can be read from the VSENSE register.

### Oscillator Frequency/External Synchronization

The internal oscillator frequency is programmable between 400kHz and 2.2MHz using a timing resistor ( $R_{RT}$ ) connected from the RT pin to GND. Use the following equation to calculate the value of  $R_{RT}$  for the desired switching frequency ( $f_{sw}$ ):

$$R_{RT} = \frac{26130}{f_{sw}} + 0.33$$

where  $R_{RT}$  is in k $\Omega$  and  $f_{sw}$  is in kHz. If the value of the RT resistor is too low or if the pin is shorted to GND, the boost converter will not start and the FLTB pin will go low.

To synchronize the oscillator with an external clock, AC-couple the external clock to the RT input. The value of the capacitor used for AC-coupling is  $C_{SYNC} = 10\text{pF}$ , and the duty cycle of the external clock should be 50%. When synchronizing the converter, do not apply the synchronizing signal to the RT pin at startup, as this may cause the RT resistor value check to fail.

At low input voltages and when the switching frequency is above 1MHz, the switching frequency is automatically reduced to enable high-duty-cycle operation and maintain output voltage regulation. This applies also when the device is synchronized to an external frequency.

### Spread Spectrum

The IC includes spread-spectrum modulation that reduces peak electromagnetic interference (EMI) at the switching frequency and its harmonics. Spread spectrum can be enabled and disabled using the SS\_OFF bit in the register SETTING\_REG.

Spread spectrum uses a pseudorandom dithering technique where the switching frequency is varied in the range of 94% to 106% or 96% to 104% (depending on the setting of the SSL bit) of the programmed switching frequency set through the external resistor from RT to GND. When spread spectrum is used, the total energy at the fundamental and each harmonic is spread over a wider bandwidth, thus reducing the peak energy at the relevant frequency.

Spread spectrum is disabled if external synchronization is used.

### LED Current Control

The IC features six identical constant-current sources used to drive multiple high-brightness LED strings. The current through each of the channels is adjustable between 34.5mA and 225mA by setting the 7-bit value iset[6:0] in the ISET\_REG register.

To accelerate device startup, the initial LED current can be set by connecting a resistor from the ISET pin to GND. With this resistor present, the ENA bit is initialized to 1, and the device starts up immediately when the EN pin is taken high. A current value determined by the resistor on ISET is loaded into the iset[6:0] field in ISET\_REG and can be adjusted subsequently using the I<sup>2</sup>C interface. Select the ISET resistor value using [Table 1](#).

**Table 1. ISET Resistor Value for a Given LED Current**

ISET RESISTOR (kΩ)	LED CURRENT PER CHANNEL (mA)	CORRESPONDING ISET REGISTER VALUE
4.3	96	0x29
9.1	106.5	0x30
15	118.5	0x38
24	130.5	0x40
33	145.5	0x4A
43	162	0x55
56	180	0x61
68	199.5	0x6E

Multiple channels can be paralleled together for string currents exceeding 225mA.

### Current-Mode DC-DC Controller

The device contains a constant-frequency, current-mode controller designed to drive the LEDs in a boost or SEPIC configuration. The IC features multiloop control to regulate the peak current in the inductor, as well as the voltage across the LED current sinks to minimize power dissipation.

Programmable slope compensation is used to avoid subharmonic oscillation that can occur at > 50% duty cycles in continuous-conduction mode.

The external nMOSFET is turned on at the beginning of every switching cycle. The inductor current ramps up linearly until turned off at the peak current level set by the feedback loop. The peak inductor current is sensed from the voltage across the current-sense resistor (R<sub>CS</sub>), which is connected from the source of the external nMOSFET to PGND.

The IC features leading-edge blanking to suppress the external nMOSFET switching noise. A PWM comparator compares the current-sense voltage plus the slope-compensation signal with the output of the transconductance error amplifier. The controller turns off the external nMOSFET when the voltage at CSP exceeds the error amplifier's output voltage (at the COMP pin). This process repeats every switching cycle to achieve peak current-mode control.

In addition to the peak current-mode-control loop, the IC has two other feedback loops for control. The converter output voltage is sensed through the BSTMON input, which is connected to the inverting input of the error amplifier. The BSTMON gain (A<sub>OVP</sub>) is defined as V<sub>OUT</sub>/V<sub>BSTMON</sub>, or (R<sub>17</sub> + R<sub>16</sub>)/R<sub>16</sub>. The other feedback comes from the OUT\_current sinks. This loop controls the headroom of the current sinks to minimize total power dissipation, while still ensuring accurate LED current. Each current sink has a window comparator with a low threshold of 0.58V and a high threshold of 0.85V. These comparators drive logic that controls an up/down counter. The up/down counter is updated on every falling edge of the DIM input and drives an 8-bit digital-to-analog converter (DAC), which sets the reference to the error amplifier.

### 9-Bit DAC

The error amplifier's reference input is controlled with a 9-bit DAC. The DAC output is ramped up during startup to implement a soft-start function (see the [Startup Sequence](#) section). During normal operation, the DAC output range is limited to between 0.482V and 0.996V. Because the DAC output is limited to no less than 0.482V during normal operation, the overvoltage threshold for the output should be set to a value less than twice the minimum LED forward voltage. The DAC LSB determines the minimum output-voltage step according to the following equation:

$$V_{STEP\_MIN} = V_{DAC\_LSB} \times A_{OVP}$$

where V<sub>STEP\_MIN</sub> is the minimum output-voltage step, V<sub>DAC\_LSB</sub> is 1.95mV (typ), and A<sub>OVP</sub> is the BSTMON resistor-divider gain (1 + R<sub>6</sub>/R<sub>7</sub>).

## Startup Sequence

The boost converter startup sequence occurs in three stages, as described in the Stage 1, Stage 2, and Stage 3 sections. The overall startup time can be selected using the fast\_ss bit in the BL\_CONFIG1 register when using the I<sup>2</sup>C interface. The boost output voltage at the end of Stage 2 differs between the slow- and fast-startup modes.

### Stage 1

After the ENA bit has been set to 1, the controller turns on the NGATE charge pump for the external nMOSFET if the V<sub>5</sub> and BATT voltages are above their respective undervoltage thresholds. The output current of the charge pump charges the gate of the external nMOSFET, thus turning it on. After a 2ms timeout expires, Stage 2 of the startup begins. If NGATE is unused, set the CP\_DIS bit in the DISABLE\_REG register to disable the NGATE charge pump.

### Stage 2

After the external MOSFET on NGATE has been enabled, the IC goes through its power-up checks, including unused string detection and OUT\_short-to-ground detection. To avoid possible damage, the converter does not start if any OUT\_ is detected as shorted to ground.

Any current sinks detected as unused are disabled to prevent a false fault-flag assertion during normal operation. After these checks have been performed, the converter begins to operate and the output voltage begins to ramp up. The DAC reference to the error amplifier is stepped upwards until the OVP pin reaches 0.48V (or 0.88V in fast-startup mode).

This stage duration is fixed at approximately 50ms (22ms in fast-startup mode).

### Stage 3

The third stage begins once the second stage is complete and the DIM input goes high. During Stage 3, the output of the converter is adjusted until the minimum OUT\_ voltage falls within the window comparator limits of 0.58V (typ) and 0.85V (typ). The output ramp is again controlled by the DAC, which provides the reference for the error amplifier. The DAC output is updated on each rising edge of the DIM input. If the DIM input is a 100% duty cycle (DIM = high), then the DAC output is updated once every 10ms.

The total soft-start time can be calculated using the following equation in slow-startup mode:

$$t_{SS} = 50ms + \frac{V_{LED} + 0.87 - (0.48 \times A_{OVP})}{f_{DIM} \times 0.01 \times A_{OVP}}$$

where t<sub>SS</sub> is the total soft-start time, 50ms is the fixed Stage 1 duration, V<sub>LED</sub> is the total forward voltage of the LED strings, 0.81V is midpoint of the window comparator, A<sub>OVP</sub> is the gain of the OVP resistor-divider, f<sub>DIM</sub> is the dimming frequency (use 100Hz if the DIM input duty cycle is 100%), and 0.01V is the maximum voltage step per clock cycle of the DAC.

In fast-startup mode (when the FAST\_SS bit in the SET\_REG register is set to 1), the following equation should be used:

$$t_{SS} = 25ms + \frac{0.88 \times A_{OVP} - (V_{LED} + 0.87)}{f_{DIM} \times 0.01 \times A_{OVP}}$$

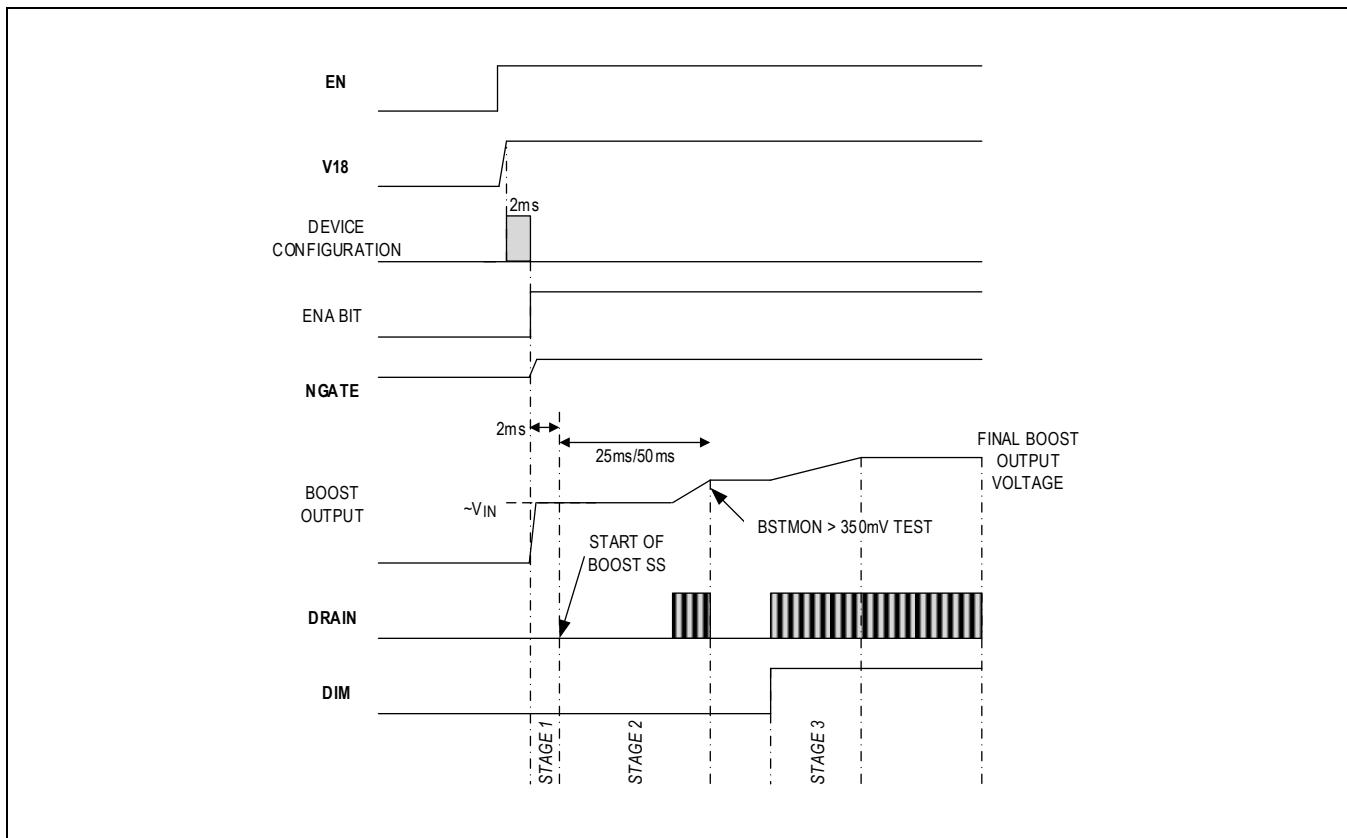


Figure 1. Start-up Sequence

### Dimming

Dimming can be performed using an external PWM signal applied to the DIM pin or by writing to the TONn\_REG registers, where n is the number of the OUT\_ pin (after setting the DIM\_EXT bit to 0). When the TON\_ALL bit is set to 1, the TON1\_value is used for all active outputs.

The signal on the DIM pin is sampled with a 20MHz internal clock, except when phase-shifting is disabled, in which case the DIM signal controls the OUT\_ outputs directly.

### Low-Dimming Mode

The IC's operation changes at very narrow dimming pulses to ensure a consistent dimming response of the LEDs. If the dimming on-time is lower than 50 $\mu$ s (typ), the device enters low-dimming mode (which is indicated by the bits in the LO\_DIM register). In this state, the converter switches continuously and LED short detection is disabled. When the DIM input is greater than 51 $\mu$ s (typ) the device goes back into normal operation, enabling the short-LED detection and switching the power FET only when the effective dimming signal is high.

### Phase-Shift Dimming

When the PSEN bit in register SET\_REG is set to 1, phase-shifting of the LED strings is enabled. To achieve this, the DIM signal is sampled internally by a 20MHz clock. The device automatically sets the phase shift between strings to a value depending on the number of strings enabled.

When phase-shifting is enabled, the sampled DIM input is used to generate separate phase-shifted dimming signals for each LED string. The resolution with which the DIM signal is captured degrades at higher DIM input frequencies; therefore, dimming frequencies between 100Hz and 3kHz are recommended, although higher dimming frequencies are technically possible. The phase shift between strings is determined by the following equation:

$$\Theta = 360/n$$

where n is the total number of strings being used and  $\Theta$  is the phase shift in degrees. See [Figure 2](#) for a timing diagram example with phase-shifting enabled.

When phase-shifting is disabled, all strings turn on/off at the same time controlled directly by the DIM input. If multiple current sinks are being connected in parallel, phase-shifting should be disabled.

If a fault is detected, resulting in a string being disabled during normal operation, the phase-shifting adjusts to the new situation.

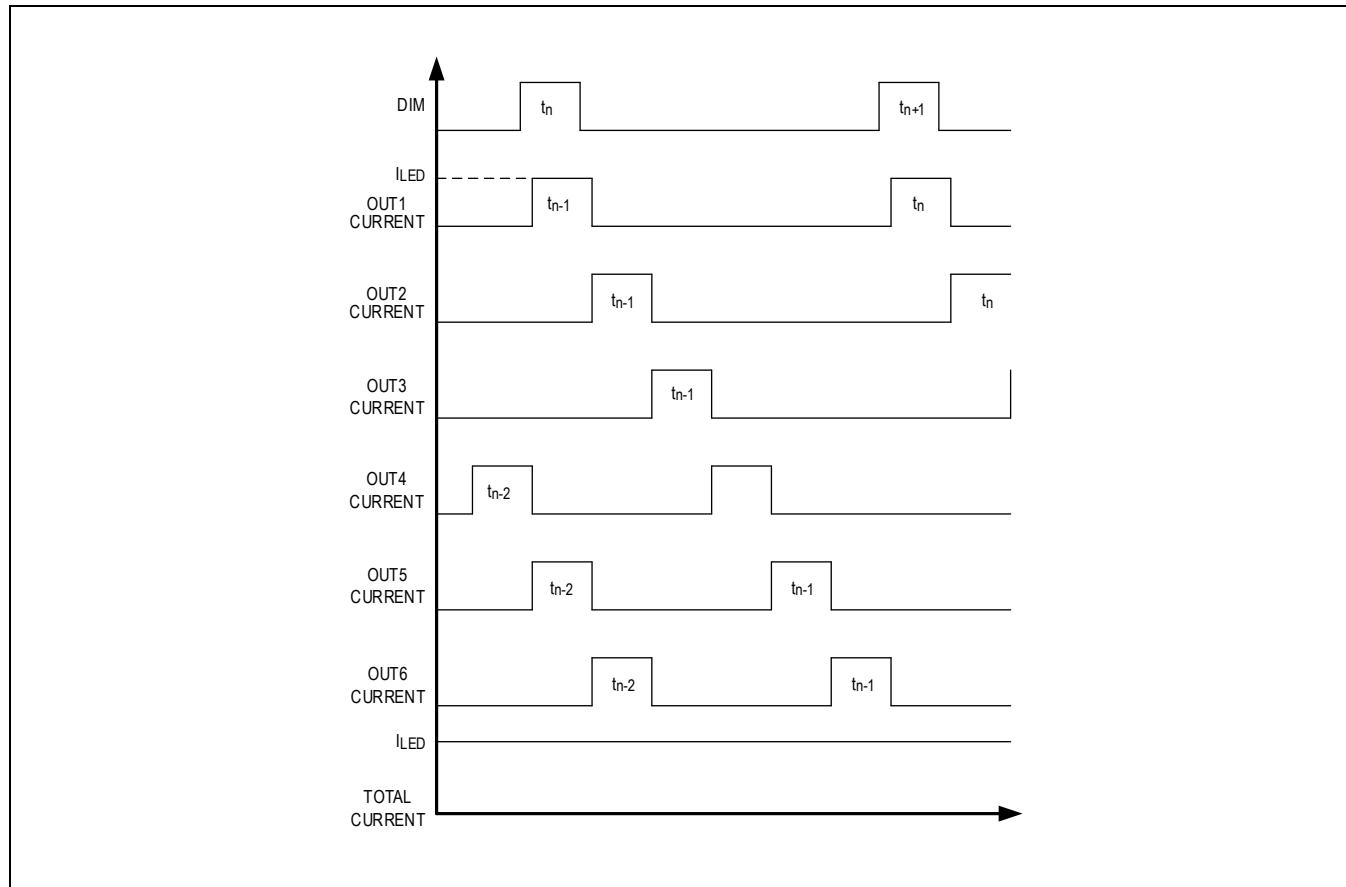


Figure 2. Phase-Shifted Outputs

### Automatic Fade-In/Fade-Out During Dimming

The device can be configured to perform a smooth change in brightness, even when the DIM input duty cycle or TON\_ setting is changed by setting the FADE\_IN\_OUT bit in the FADING\_REG register to 1.

When using the fade function, it is important to maintain the DIM frequency constant when entering 100% duty cycle. This is necessary in order to avoid erroneous frequency measurement, which could change the speed of the fade-in.

### Disabling Individual Strings

To disable an unused LED string, connect the unused OUT\_ to ground through a 9.1k $\Omega$  resistor, or set the corresponding DIS\_ bit to 1 in the DISABLE register before the ENA bit is set. During startup, the device sources 60 $\mu$ A (typ) current through the OUT\_ pins and measures the corresponding voltage. For the string to be properly disabled, the OUT\_ voltage should measure between the maximum value of V<sub>OUT\_GND</sub> and the minimum value of V<sub>OUT\_UN</sub> during this check.

**Note:** When disabling unused strings, it is necessary to start by disabling the highest numbered current sinks first (e.g., if two strings need to be disabled, disable OUT6 and OUT5. Do not disable any two strings at random). During normal operation, strings can be selectively turned off by changing the corresponding TON\_ setting to 0. This is only possible when internal dimming is used (not when using the DIM input pin).

### Hybrid Dimming

To invoke hybrid dimming mode, set the HDIM bit in register IMODE\_REG. In hybrid dimming mode, the external LEDs are dimmed by first reducing their current as the dimming duty cycle decreases from 100% (see [Figure 3](#)). At the crossover

level set by the HDIM\_THR\_1\_0[1:0] bits, dimming transitions to PWM dimming where the LED current is chopped. Depending on the DIM\_EXT bit, the device functions in one of two ways:

- (DIM\_EXT = 1) measures the duty cycle on the DIM pin and translates it into a combined LED current value and PWM setting.
- (DIM\_EXT = 0) takes the 18-bit value from the TON1 register and translates it into a combined LED current value and PWM setting.

[Figure 3](#) illustrates the difference between standard and hybrid dimming with phase-shifting enabled.

### Hybrid Dimming Operation

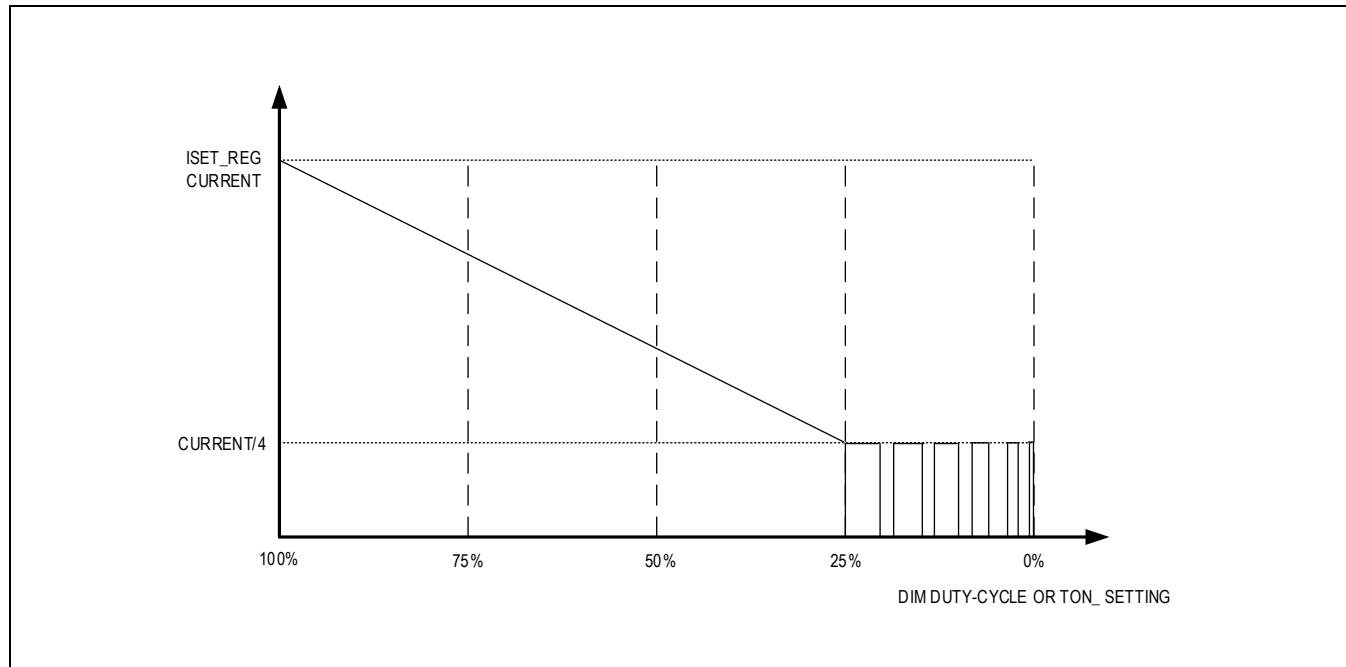


Figure 3. Hybrid Dimming Operation with HDIM[1:0] = 10 (25%)

### Temperature Foldback

In standalone mode, when an NTC temperature sensor is connected between GND and a resistor (RT1) that is connected to the V18 supply, with a further resistor (RT2) connected from the junction of the NTC and RT1 to the TEMP pin, temperature foldback is implemented. When the temperature reaches the temperature T1 (set by RT1), the current in the LEDs is reduced according to the linear scheme shown in [Figure 4](#). The slope of the current reduction is set by RT2. The MAX25561 is specifically designed to be used with the NTCLE100E3 or a similar NTC device. [Table 2](#) illustrates some examples of values of RT1 and RT2 to obtain certain values of T1 and T<sub>DELTA</sub>.

**Table 2. Temperature Resistor Values**

RT1 (kΩ)	RT2 (kΩ)	T1 (°C)	T <sub>DELTA</sub> (°C)
6.04	1.2	70	30
6.04	2	70	50

When the temperature reaches T1, the OTW bit in register DIAG\_REG is asserted. When the temperature reaches T<sub>OFF</sub>, the LED current is turned off, the bl\_low bit is set high, and the FLTB pin asserts low.

### Temperature Foldback with OUT\_Current Mismatch Diagnostic

When temperature foldback is used in conjunction with the current mismatch, diagnostic current mismatch will be indicated at some point above T1.

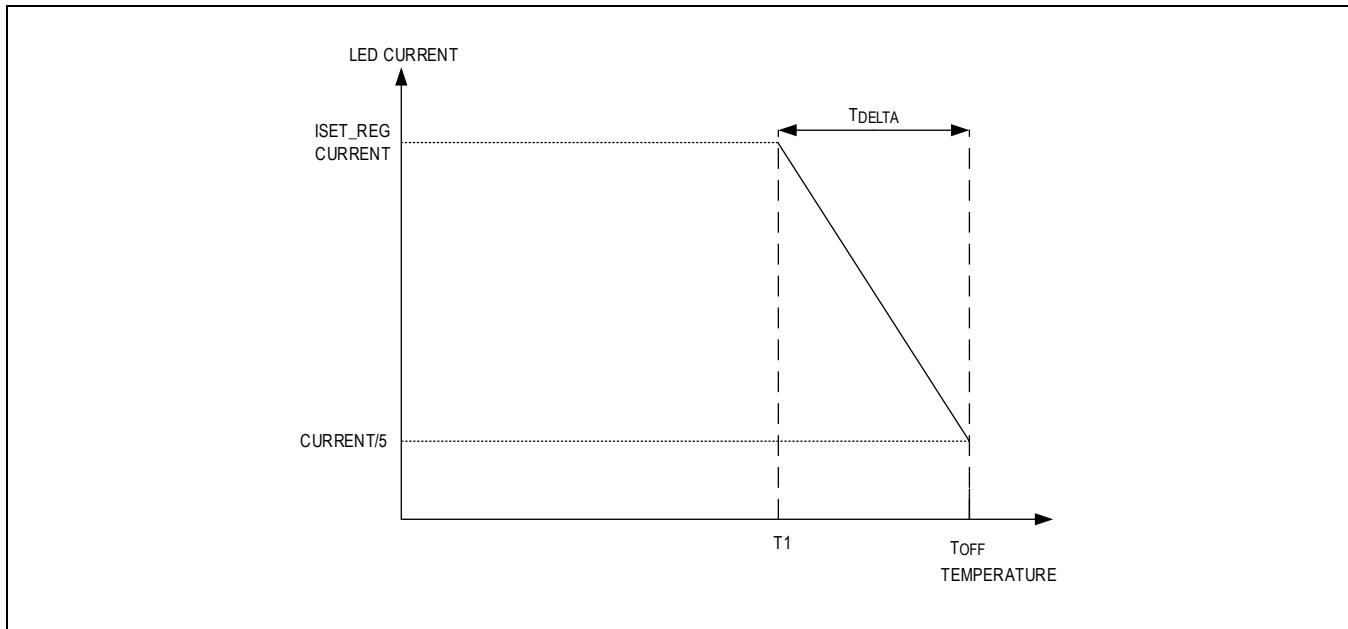


Figure 4. Temperature Foldback Curve

#### TEMP External Circuit

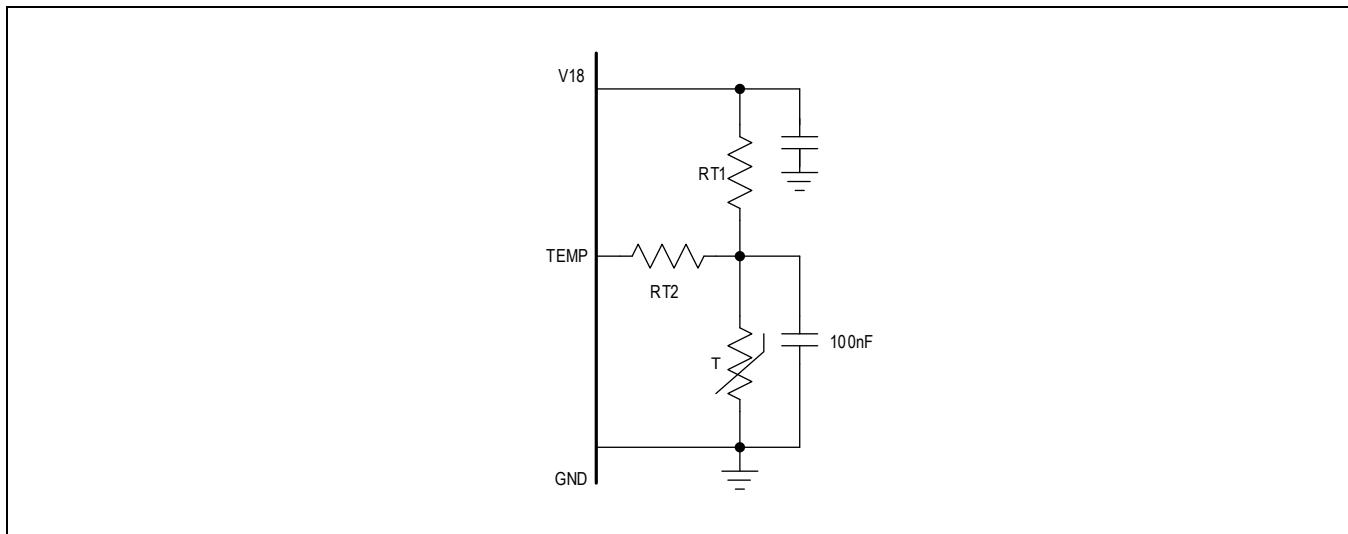


Figure 5. TEMP External Circuit

### Hybrid Dimming Operation Modes

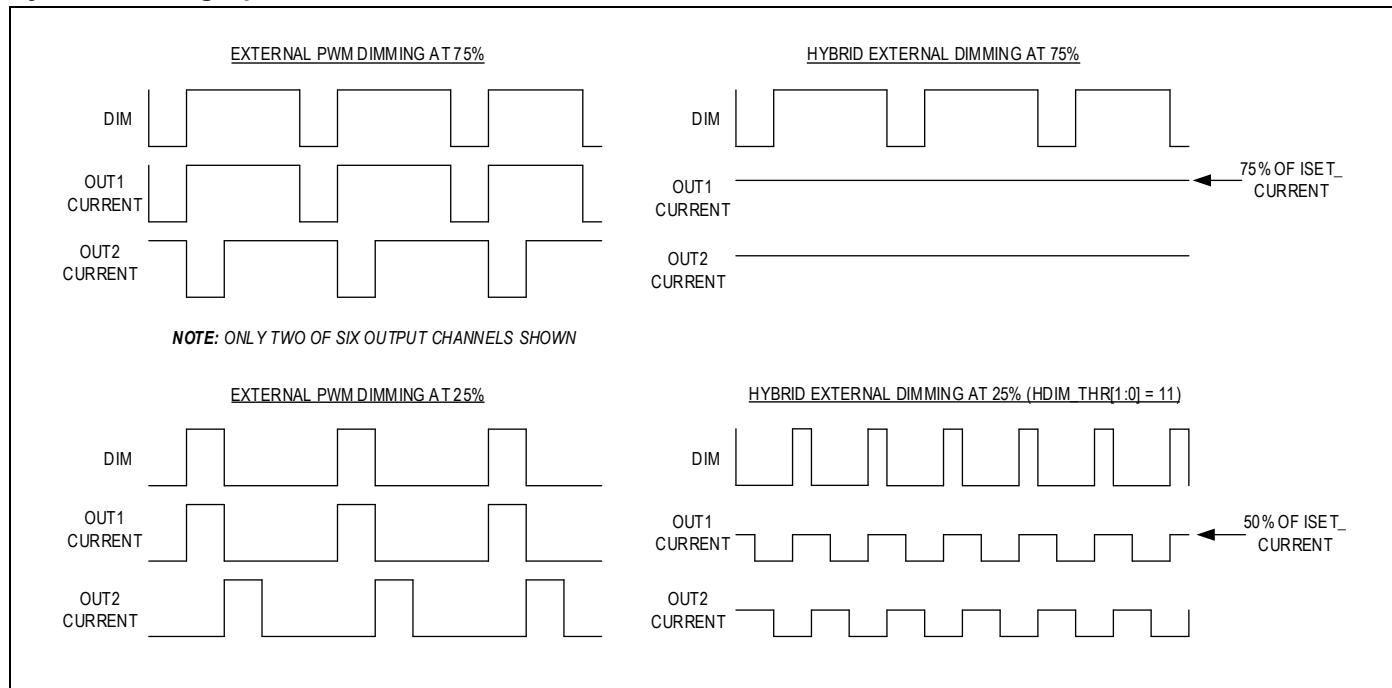


Figure 6. Hybrid Dimming Operation Modes

### Diagnostics and FLT<sub>B</sub> Output

The open-drain fault flag output (FLT<sub>B</sub>) goes low when a fault is detected. Certain faults can be inhibited from causing FLT<sub>B</sub> to go low using the bits in the MASK1 and MASK2 registers.

FLT<sub>B</sub> asserts low for the following faults if not masked (note that not all faults can be masked):

- OUT<sub>\_</sub> open, shorted LED, short to ground
- OUT<sub>\_</sub> current mismatch, OUT<sub>\_</sub> TON I/O mismatch
- RT out of range, IREF out of range, ISET out of range, VREF out of range
- Boost undervoltage, V18 out-of-range, V5 out-of-range
- Interface PEC error, clock error, internal nonvolatile memory error
- Undervoltage on BATT, boost input overcurrent
- Overtemperature warning

### Open-LED Management and Overvoltage Protection

After the soft-start of the boost converter, the IC detects open-LED strings and disconnects any such strings from the internal minimum OUT<sub>\_</sub> voltage detector. This keeps the DC-DC converter output voltage within correct limits and maintains high efficiency. The current in strings that have been detected open is not measured by the ADC and reads as zero.

During normal operation, the DC-DC converter output-regulation loop uses the minimum OUT<sub>\_</sub> voltage as the feedback input. If any LED string is open, the voltage at the opened OUT<sub>\_</sub> goes to V<sub>LEDGND</sub>. The DC-DC converter output voltage then increases to the overvoltage-protection threshold set by the voltage-divider network connected between the converter output, the BSTMON input, and GND. The overvoltage-protection threshold at the DC-DC converter output is determined using the following equation:

$$V_{OUT\_BSTMON} = 0.95 \times \left(1 + \frac{R16}{R17}\right)$$

where 0.95V (typ) is the overvoltage threshold on BSTMON (see the [Functional Diagram](#)). Select V<sub>OUT<sub>\_</sub> BSTMON</sub> according to the following formula:

$$1.1 \times (V_{LED_{MAX}} + 0.87) < V_{OUT_{BSTMON}} < 2 \times (V_{LED_{MIN}} + 0.55)$$

where:

$V_{LED\_MAX}$  = Maximum expected LED string voltage

$V_{LED\_MIN}$  = Minimum expected LED string voltage

Select R16 and R17 such that the voltage at OUT\_ does not exceed the absolute maximum rating. As soon as the DC-DC converter output reaches the overvoltage-protection threshold, the internal MOSFET is switched off. The overvoltage threshold should be set to less than twice the minimum LED voltage to ensure proper operation and that the BSTMON minimum regulation point of 600mV (typ) is not breached. When an open-LED overvoltage condition occurs, FLT\_B is latched low.

If all active OUT\_ channels are detected as open, the boost converter is disabled. Toggle the EN pin or cycle the power supply to clear an open-LED condition.

### Short-LED Detection

The IC checks for shorted LEDs after the current in any channel is turned on. A shorted-LED is detected at OUT\_ if the following condition is met:

$$V_{OUT\_} > RSDT$$

Where RSDT is the programmable short-LED-detection threshold set by the SLDET[1:0] bits in the SETTING\_REG register.

If a short is detected on any of the strings, the affected LED strings are disabled after a delay of one dimming cycle and the FLT\_B output flag asserts low after two dimming cycles until the device detects that the shorts are removed. Disable short-LED detection by setting SLDET[1:0] to 0x0. Short-LED detection is disabled in low-dimming mode. In external dimming mode with the DIM input connected continuously high, the OUT\_ pins are periodically scanned to detect shorted LEDs. The scan frequency is 100Hz. Similarly, when DIM\_EXT = 0 and internal dimming is being used, shorted LEDs are still detected by periodically scanning the OUT\_ states at 100Hz.

Short-LED detection is also disabled in cases where all active OUT\_ channels rise above 2.5V. This can occur in a boost-converter application when the input voltage becomes higher than the total LED string voltage drop, such as during a battery load dump. If a short-LED fault occurs during a load dump, the fault flag does not assert until the load dump is over and the minimum OUT\_ voltage has fallen below 2.35V. If a load dump occurs after a short LED is detected, the fault flag deasserts until the load dump is over and the minimum OUT\_ voltage has fallen below 2.35V, at which point, the fault flag reasserts.

### LED Short-to-Ground Protection

During startup, a check is performed for OUT\_ pins shorted to ground by sourcing a current of 60 $\mu$ A into the OUT\_ pins. If the pin voltage does not exceed  $V_{OUT\_GND}$ , a short to GND is declared. In this case, the device does not start. Toggle the EN pin or power to clear this condition.

### Analog-to-Digital Converter (ADC)

The 8-bit ADC is used to measure the current in each of the strings, the voltage on the BSTMON pin, and the voltage between the BATT and ISENSE pins. The reference for the ADC is the second redundant bandgap. The ADC is free-running and begins operation at the beginning of Stage 3 of boost startup and is disabled whenever the boost converter is disabled (by the ENA bit or due to any fault which disables the converter). When the ADC is disabled after a fault, the last ADC conversion results are maintained in the appropriate registers.

The ADC cycles continuously between OUT1-6, VBSTMON, and VBATT-ISENSE. At the end of each cycle, the IOUT1-IOUT6 and VBSTMON registers contain the updated values. The full-scale value of the current measurement is 255mA (resolution 1mA) with an IREF resistor of 22k $\Omega$ . Conversions of channels that are in low-dim mode yield a value of 0x00. Similarly, any channels that are disabled, open-circuit, or in the shorted-LED condition will read zero current.

The full-scale value of the BSTMON pin voltage conversion is 1V with a resolution of 3.92mV. The full-scale value of the VBATT-ISENSE measurement is 255mV. Values higher than full scale read as 0xFF.

The duration of a complete conversion depends on whether or not phase-shifting is enabled. With phase-shifting enabled, a complete conversion can take up to two dimming cycles. With phase-shifting disabled, one dimming cycle is the worst-case latency (the conversion is initiated at the beginning of a DIM cycle and concluded < 50 $\mu$ s later).

### Measured OUT\_Current Mismatch

Using the MM\_MODE bit, the behavior of the device when an output current mismatch is detected can be selected:

- When MM\_MODE is 0, a mismatch of more than 20 bits causes FLTB to assert low. No other action is taken.
- When MM\_MODE is 1, a mismatch of more than 20 bits causes FLTB to assert low and the device to stop operation.

The current mismatch check is disabled during the soft-start of the boost converter and under the following conditions:

- When a channel is below the OUT regulation low threshold
- When a channel is in low-dim mode
- When a channel is set to zero brightness (internal dimming)
- When hybrid dimming is enabled
- After a write to the iset[6:0] field; the check is then disabled for two DIM cycles

To clear a current mismatch fault, the EN pin, ENA bit, or device power must be toggled.

### VREF Out-of-Range Detection

The device contains two separate bandgap references which are continuously compared to each other. If the difference between the two is greater than 8%, the FLTB pin is asserted low and the VREFOOR bit in the DIAG2\_REG register is set to 1. No further action is taken; if desired, the host can disable the device using the EN pin.

### V5 Out-of-Range Detection

The device monitors the V5 gate drive voltage and, if the voltage is detected to be above the overvoltage threshold or below the undervoltage threshold, device operation ceases, the FLTB pin is asserted low, and the V5OOR bit in the DIAG2\_REG register is set to 1.

### Clock Error

The internal device clock is monitored continuously. If the clock is inactive for more than 1ms or is out of range, the CLK\_ERR bit in DIAG2\_REG is set to 1 and the FLTB pin is asserted low. When this fault occurs, the FLTB pin asserts low and the local microcontroller should disable the device using the EN pin. This fault can only be cleared by power-on reset (POR).

### Input/Output On-Time Comparison

The device monitors the OUT\_voltage after the output is turned off to ensure that the output duty cycle is not larger than the input duty cycle. The voltage threshold used is set by the SLDET[1:0] bits. When using this diagnostic, a resistor of value 20kΩ should be connected from each OUT\_pin to the output of the boost converter.

The timing diagram in [Figure 7](#) shows the sequence of events with phase-shifting disabled (though the scheme will work equally with phase-shift enabled). At time t1, the DIM input goes high and, after a short delay, the OUT\_current sink turns on and pulls the voltage at OUT\_low. A comparator monitoring OUT\_detects that the OUT\_voltage has fallen below a threshold. At time t2, DIM returns low and, if there is no malfunction, the voltage on OUT\_returns high and the comparator output goes low. At a defined time after the DIM signal has gone low (tDEL = 100μs), the comparator output is continuously monitored. If the comparator output goes high, an error is detected. This check may not function at duty cycles with an off-time of less than 100μs.

When this error is detected, the corresponding bit in the TON\_MISMATCH register is set and FLTB is asserted low (unless masked using the TON\_MM\_MASK bit). In addition, the bit MM\_MODE determines whether the device is automatically disabled:

- When MM\_MODE is 0, a TON mismatch is indicated, but no further action is taken.
- When MM\_MODE is 1, a TON mismatch causes the device to stop operation. After device operation is stopped, it can be restarted by toggling power, the EN input pin, or the ENA bit.

This check can be disabled globally using the TON\_MM\_DIS bit in the MM\_DIS register or individually for any of the outputs using the TONn\_MM\_DIS bits where n is the number of the output from 1 to 6.

To clear a TON mismatch fault, the EN pin or device power must be toggled.

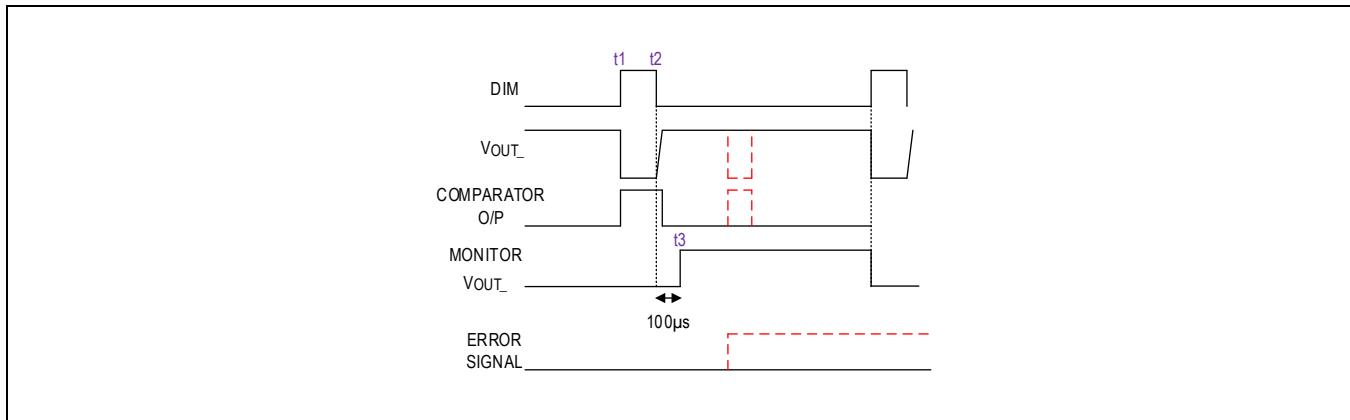


Figure 7. Input/Output On-Time Comparison

### Thermal Warning/Shutdown

The IC includes thermal protection that operates at a temperature of  $+160^{\circ}\text{C}$ . When the thermal-shutdown temperature is reached, the device is immediately disabled so it can cool. When the junction temperature falls by  $17^{\circ}\text{C}$ , the device is reenabled with the same settings as before (the boost converter performs a soft-start). When a thermal shutdown occurs, the FLT<sub>B</sub> pin goes low and the OT bit in the DIAG1\_REG register is set to 1.

A thermal warning bit (OTW) is also implemented in the DIAG1\_REG register and indicates that the junction temperature has exceeded  $+125^{\circ}\text{C}$ . The OTWMASK bit in the MASK1\_REG register controls whether or not an active OTW bit causes the FLT<sub>B</sub> pin to go low.

### I<sup>2</sup>C Interface

The MAX25561 features an I<sup>2</sup>C, two-wire serial interface consisting of a serial-data line (SDA) and a serial-clock line (SCL).

SDA and SCL facilitate communication between the device and the controller at clock rates up to 400kHz. The controller, typically a microcontroller, generates SCL and initiates data transfer on the bus. [Figure 8](#) shows the two-wire interface timing diagram.

A controller device communicates with the device by transmitting the correct address followed by the data word. Each transmit sequence is framed by a START (S) or REPEATED START (Sr) condition and a STOP (P) condition. Each word transmitted over the bus is 8 bits long and is always followed by an acknowledge clock pulse.

The SDA line operates as both an input and an open-drain output. A pull-up resistor greater than  $500\Omega$  is required on the SDA bus. The SCL line operates as an input only. A pull-up resistor greater than  $500\Omega$  is required on SCL if there are multiple controllers on the bus, or if the controller in a single-controller system has an open-drain SCL output. Series resistors in line with SDA and SCL are optional. The SCL and SDA inputs suppress noise spikes to assure proper device operation, even on a noisy bus.

### Bit Transfer

One data bit is transferred during each SCL cycle. The data on SDA must remain stable during the high period of the SCL pulse. Changes in SDA while SCL is high are control signals (see the [STOP and START Conditions](#) section). SDA and SCL idle high when the I<sup>2</sup>C bus is not busy.

### STOP and START Conditions

A controller device initiates communication by issuing a START condition. A START condition is a high-to-low transition on SDA with SCL high. A STOP condition is a low-to-high transition on SDA while SCL is high ([Figure 8](#)). A START (S) condition from the controller signals the beginning of a transmission to the device. The controller terminates transmission and frees the bus by issuing a STOP (P) condition. The bus remains active if a REPEATED START (Sr) condition is generated instead of a STOP condition.

### Early STOP Condition

The MAX25561 recognizes a STOP condition at any point during data transmission except if the STOP condition occurs in the same high pulse as a START condition.

### Clock Stretching

In general, the clock signal generation for the I<sup>2</sup>C bus is the responsibility of the controller device. The I<sup>2</sup>C specification allows slow target devices to alter the clock signal by holding down the clock line, a process that is typically called clock stretching. The MAX25561 does not use clock stretching to hold down the clock line.

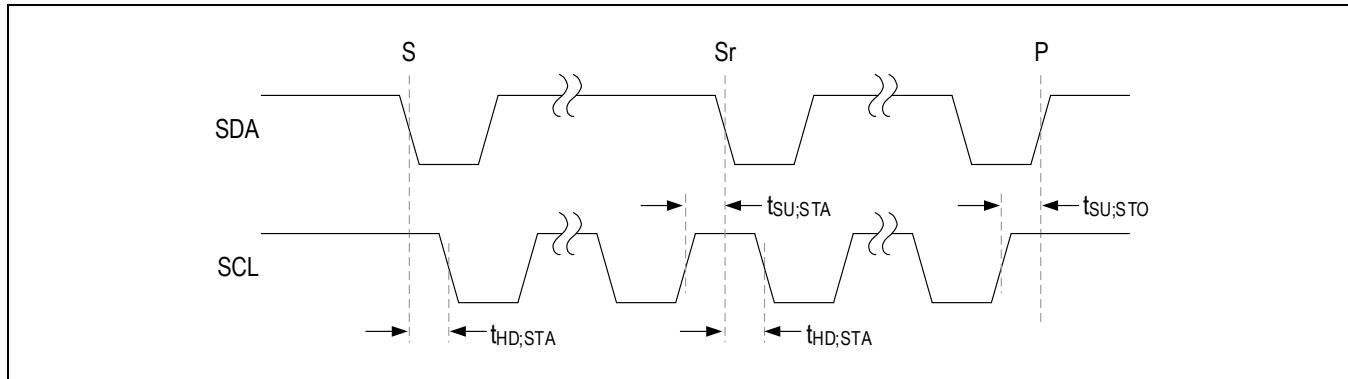


Figure 8. START, STOP, and REPEATED START Conditions

### I<sup>2</sup>C General Call Address

The IC does not implement the I<sup>2</sup>C specification's general call address. The device will not issue an acknowledge to the general call address (0b0000\_0000).

### Packet Error Checking (PEC)

In order to increase fault coverage on the I<sup>2</sup>C interface, an optional PEC byte is supported. The PEC is enabled by setting the PEC\_EN bit in the SET\_REG register to 1. This follows the SMBus 3.0 implementation, which has a CRC-8 polynomial of  $x^8 + x^2 + x + 1$ . If the PEC byte is enabled and a supervisor system attempts to read more than 2 bytes (one data and one PEC) from the IC in a single communication packet, the IC will return 0xFF for the remaining bytes read. If a controller device transmits a byte and an incorrect PEC, the IC will reply with a NACK and discard the attempted write.

### Acknowledge

The acknowledge bit (ACK) is a clocked ninth bit that the device uses to handshake receipt of each byte of data (see [Figure 9](#)). The device pulls down SDA during the controller-generated ninth clock pulse. The SDA line must remain stable and low during the high period of the acknowledge clock pulse. Monitoring ACK allows for detection of unsuccessful data transfers. An unsuccessful data transfer occurs if a receiving device is busy or if a system fault has occurred. In the event of an unsuccessful data transfer, the bus controller can reattempt communication. Transmitting an incorrect PEC byte to the device (when PEC is enabled) will also result in a NACK from the IC (in addition, the PEC\_ERR bit is set to 1 and FLT\_B is asserted low if the PEC\_ERRMASK bit is 0).

### Target Address

The I<sup>2</sup>C addresses are shown in [Table 3](#).

Table 3. I<sup>2</sup>C Addresses

ADD PIN CONNECTION	7-BIT ADDRESS	8-BIT READ ADDRESS	8-BIT WRITE ADDRESS
GND	0x27	0x4F	0x4E
V18	0x2F	0x5F	0x5E

The address is defined as the 7 most significant bits (MSbs) followed by the R/W bit. Set the R/W bit to 1 to configure the device to read mode. Set the R/W bit to 0 to configure the device to write mode. The address is the first byte of information sent to the device after the START condition.

### Write-Data Format

A write to the device includes transmission of a START condition, the target address with the R/W bit set to 0, one byte of data to register address, one to eight bytes of data to write to registers, and a STOP condition. [Figure 9](#) illustrates the proper format for one frame. If multiple bytes are transmitted, they are written to sequential registers starting at the register address transmitted. If the register address for the write reaches the end of the valid address space, the target register

pointer will stay at the last valid register. If the write starts out-of-bounds, then all the bytes written will be discarded and the IC will return a NACK for each byte transmitted.

### Read-Data Format

A read from the device includes the following:

- Transmission of a START condition
- Target address with the R/W bit set to 0
- 1 byte of data to register address
- Restart condition
- Target address with R/W bit set to 1
- 1-8 bytes written by the IC
- STOP condition

[Figure 9](#) illustrates the correct frame format. The controller device must acknowledge each byte received and provide a NACK at the last byte read.

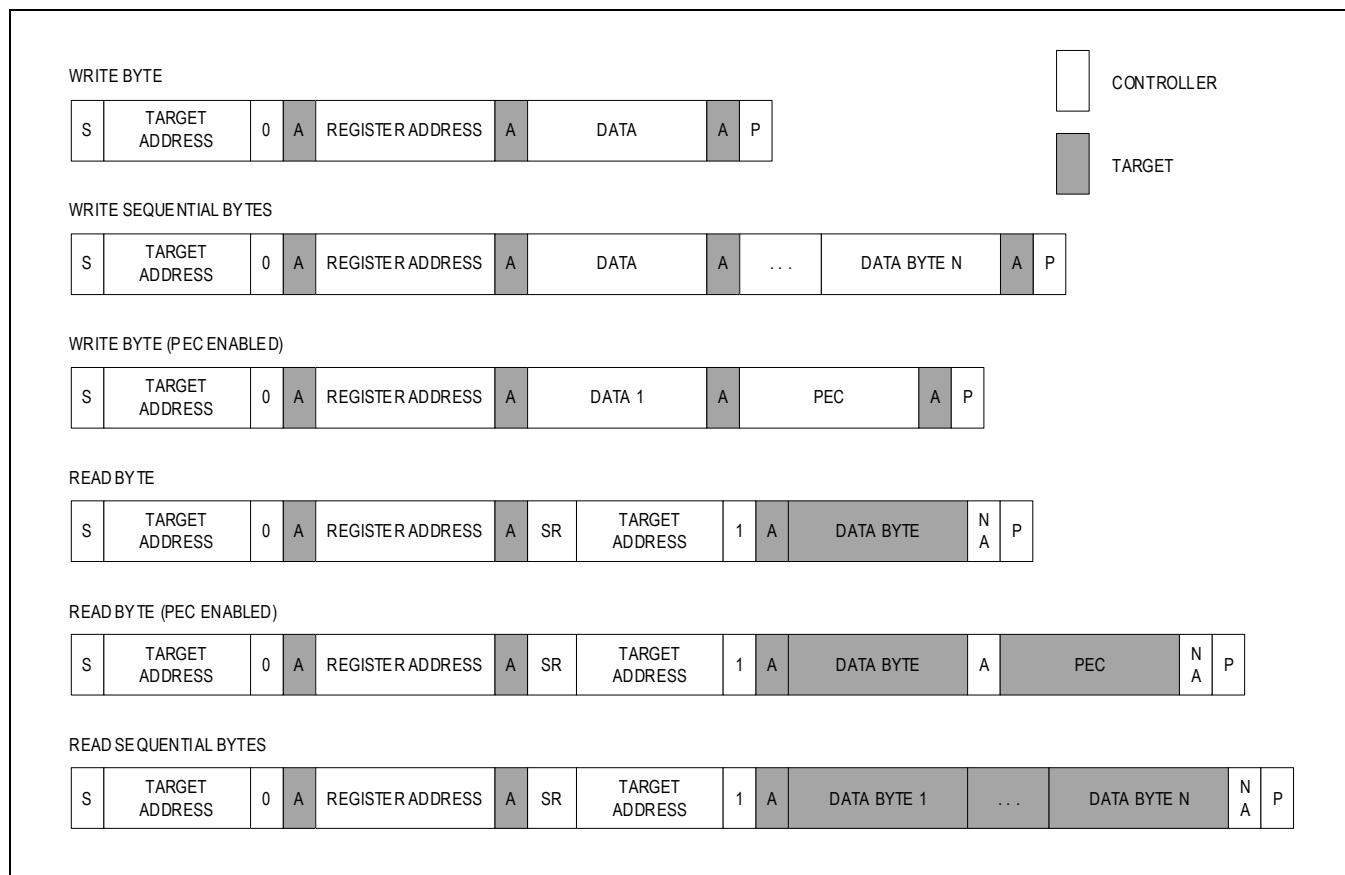


Figure 9. Data Format of I<sup>2</sup>C Interface

## Register Map

MAX25561

ADDRESS	NAME	MSB						LSB
USER_REGISTERS								

ADDRESS	NAME	MSB							LSB									
0x00	<u>DEV_ID_REG[7:0]</u>		DEV_ID[7:0]															
0x01	<u>REV_ID_REG[7:0]</u>	-	-	-	-	REV_ID[3:0]												
0x02	<u>SET_REG[7:0]</u>	-	-	PEC_EN	BL_ILIM	BSTFORC_E	FAST_SS	ENA	PSEN									
0x03	<u>IMODE_REG[7:0]</u>	-	-	-	DIS_ISNS_SD	DIM_EXT	HDIM	HDIM_THR_1_0[1:0]										
0x04	<u>ISET_REG[7:0]</u>	-	iset[6:0]															
0x05	<u>TON1H_REG[7:0]</u>		TON1H[7:0]															
0x06	<u>TON1L_REG[7:0]</u>		TON1L[7:0]															
0x07	<u>TON2H_REG[7:0]</u>		TON2H[7:0]															
0x08	<u>TON2L_REG[7:0]</u>		TON2L[7:0]															
0x09	<u>TON3H_REG[7:0]</u>		TON3H[7:0]															
0x0A	<u>TON3L_REG[7:0]</u>		TON3L[7:0]															
0x0B	<u>TON4H_REG[7:0]</u>		TON4H[7:0]															
0x0C	<u>TON4L_REG[7:0]</u>		TON4L[7:0]															
0x0D	<u>TON1_4LSB_REG[7:0]</u>	TON4LSB[1:0]		TON3LSB[1:0]		TON2LSB[1:0]		TON1LSB[1:0]										
0x0E	<u>TON5H_REG[7:0]</u>		TON5H[7:0]															
0x0F	<u>TON5L_REG[7:0]</u>		TON5L[7:0]															
0x10	<u>TON6H_REG[7:0]</u>		TON6H[7:0]															
0x11	<u>TON6L_REG[7:0]</u>		TON6L[7:0]															
0x12	<u>TON5_6LSB_REG[7:0]</u>	-	-	-	TON_ALL	TON6LSB[1:0]			TON5LSB[1:0]									
0x13	<u>SETTING_REG[7:0]</u>	MM_MODE	FPWM[2:0]			SS_OFF	SSL	SLDET[1:0]										
0x14	<u>DISABLE_REG[7:0]</u>	-	SLDET_DIS	CP_DIS	DIS6	DIS5	DIS4	DIS3	DIS2									
0x15	<u>FADING_REG[7:0]</u>	-	-	-	FADE_GAIN	FADE_IN_OUT	TDIM[2:0]											
0x16	<u>LO_DIM[7:0]</u>	-	-	LO_DIM6	LO_DIM5	LO_DIM4	LO_DIM3	LO_DIM2	LO_DIM1									

ADDRESS	NAME	MSB							LSB
0x17	<u>OPEN_REG[7:0]</u>	-	-	OUT6O	OUT5O	OUT4O	OUT3O	OUT2O	OUT1O
0x18	<u>SHORTGND_REG[7:0]</u>	-	-	OUT6SG	OUT5SG	OUT4SG	OUT3SG	OUT2SG	OUT1SG
0x19	<u>SHORTED_LED_REG[7:0]</u>	-	-	OUT6SL	OUT5SL	OUT4SL	OUT3SL	OUT2SL	OUT1SL
0x1A	<u>MASK1_REG[7:0]</u>	-	-	-	BSTUVMA_SK	OMASK	SGMASK	OTWMASK	SLMASK
0x1B	<u>MASK2_REG[7:0]</u>	TON_MM_MASK	PEC_ERRMASK	BATT_UVMASK	I_MM_MASK	-	-	-	-
0x1C	<u>DIAG1_REG[7:0]</u>	RTOOR	ISETOOR	IREFOOR	BSTUV	BSTOV	HW_RST	OTW	OT
0x1D	<u>DIAG2_REG[7:0]</u>	V18OOR	PEC_ERR	BATT_UV	CLK_ERR	V5OOR	VREFOOR	NV_FLT	ISNS_SD
0x1E	<u>I_MMISMATCH[7:0]</u>	-	-	I_MM6	I_MM5	I_MM4	I_MM3	I_MM2	I_MM1
0x1F	<u>TON_MMISMATCH[7:0]</u>	-	-	TON6_MM	TON5_MM	TON4_MM	TON3_MM	TON2_MM	TON1_MM
0x20	<u>MM_DIS[7:0]</u>	I_MM_DIS	TON_MM_DIS	TON6_MM_DIS	TON5_MM_DIS	TON4_MM_DIS	TON3_MM_DIS	TON2_MM_DIS	TON1_MM_DIS
0x21	<u>VBSTMON[7:0]</u>						vbstmon[7:0]		
0x22	<u>IOUT1[7:0]</u>						iout1[7:0]		
0x23	<u>IOUT2[7:0]</u>						iout2[7:0]		
0x24	<u>IOUT3[7:0]</u>						iout3[7:0]		
0x25	<u>IOUT4[7:0]</u>						iout4[7:0]		
0x26	<u>IOUT5[7:0]</u>						iout5[7:0]		
0x27	<u>IOUT6[7:0]</u>						iout6[7:0]		
0x28	<u>VSENSE[7:0]</u>						vsense[7:0]		
0x29	<u>DIM_TON_HI[7:0]</u>						dim_ton_hi[7:0]		
0x2A	<u>DIM_TON_MID[7:0]</u>						dim_ton_mid[7:0]		
0x2B	<u>DIM_TON_LO[7:0]</u>	-	-	-	-	-	-	dim_ton_lo[1:0]	
0x2C	<u>DIM_F_HI[7:0]</u>						dim_f_hi[7:0]		
0x2D	<u>DIM_F_MID[7:0]</u>						dim_f_mid[7:0]		

ADDRESS	NAME	MSB							LSB
0x2E	<u>DIM_F_LO[7:0]</u>	–	–	–	–	–	–	–	dim_f_lo[1:0]

## Register Details

### DEV\_ID\_REG (0x0)

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	DEV_ID[7:0]							
<b>Reset</b>								
<b>Access Type</b>	Read Only							

BITFIELD	BITS	DESCRIPTION
DEV_ID	7:0	Device ID

### REV\_ID\_REG (0x1)

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	–	–	–	–	REV_ID[3:0]			
<b>Reset</b>	–	–	–	–	0x1			
<b>Access Type</b>	–	–	–	–	Read Only			

BITFIELD	BITS	DESCRIPTION
REV_ID	3:0	Device revision ID.

### SET\_REG (0x2)

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	–	–	PEC_EN	BL_ILIM	BSTFORCE	FAST_SS	ENA	PSEN
<b>Reset</b>	–	–	0b0	0b0	0b0	0b0	0b0	0b0
<b>Access Type</b>	–	–	Write, Read					

BITFIELD	BITS	DESCRIPTION	DECODE
PEC_EN	5	When 1, PEC is enabled on I <sup>2</sup> C transactions.	
BL_ILIM	4	Sets boost current limit to one of two levels. When 0, the higher current limit is selected.	0x0: Current limit set high 0x1: Current limit set low
BSTFORCE	3	When 1, this bit forces the boost converter to run continuously and independently of the dimming signal.	
FAST_SS	2	Selects slow or fast boost soft-start. Set to 1 for fast soft-start.	
ENA	1	Boost converter and LED outputs enable bit. Set to 1 to enable the device.	
PSEN	0	When 0, phase shifting is disabled. When 1, phase shifting is enabled.	

IMODE REG (0x3)

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	–	–	–	DIS_ISNS_SD	DIM_EXT	HDIM	HDIM_THR_1_0[1:0]	
<b>Reset</b>	–	–	–	0x0	0b1	0b0	0b00	
<b>Access Type</b>	–	–	–	Write, Read	Write, Read	Write, Read	Write, Read	

BITFIELD	BITS	DESCRIPTION								
DIS_ISNS_SD	4	When 1, this bit disables the input overcurrent shutdown function. When an overcurrent is detected, the ISNS_SD bit is asserted, but the device continues operation and FLTB does not assert low.								
DIM_EXT	3	When 1, dimming through the DIM pin is enabled. When 0, dimming is controlled using the TON_ registers.								
HDIM	2	When 1, hybrid dimming is enabled.								
HDIM_THR_1_0	1:0	Set hybrid dimming threshold. <table border="1" data-bbox="693 1636 1468 1869"> <tr> <td>00</td> <td>6.25%</td> </tr> <tr> <td>10</td> <td>12.5%</td> </tr> <tr> <td>10</td> <td>25%</td> </tr> <tr> <td>11</td> <td>50%</td> </tr> </table>	00	6.25%	10	12.5%	10	25%	11	50%
00	6.25%									
10	12.5%									
10	25%									
11	50%									

**ISET REG (0x4)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	—	iset[6:0]						
<b>Reset</b>	—	0b0001000						
<b>Access Type</b>	—	Write, Read						

BITFIELD	BITS	DESCRIPTION	DECODE
iset	6:0	The value in this register sets the OUT_LED current in the range 93mA to 220mA.	0x00: 34.5mA 0x01: 36mA ...: ... 0x2B: 99mA 0x2C: 100.5mA 0x2D: 102mA ...: ... 0x7D: 222mA 0x7E: 223.5mA 0x7F: 225mA

**TON1H REG (0x5)**

On-time setting for channel 1 with 50ns resolution, high byte.

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	TON1H[7:0]							
<b>Reset</b>	0xFF							
<b>Access Type</b>	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON1H	7:0	High byte of 18-bit TON setting for channel 1.

**TON1L REG (0x6)**

On-time setting for channel 1 with 50ns resolution, middle byte.

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	TON1L[7:0]							
<b>Reset</b>	0xFF							
<b>Access Type</b>	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON1L	7:0	Middle byte of 18-bit TON setting for channel 1.

### TON2H REG (0x7)

On-time setting for channel 2 with 50ns resolution2, high byte.

BIT	7	6	5	4	3	2	1	0
Field	TON2H[7:0]							
Reset	0xFF							
Access Type	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON2H	7:0	High byte of 18-bit TON setting for channel 2.

### TON2L REG (0x8)

On-time setting for channel 2 with 50ns resolution, middle byte.

BIT	7	6	5	4	3	2	1	0
Field	TON2L[7:0]							
Reset	0xFF							
Access Type	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON2L	7:0	Middle byte of 18-bit TON setting for channel 2.

### TON3H REG (0x9)

On-time setting for channel 3 with 50ns resolution, high byte.

BIT	7	6	5	4	3	2	1	0
Field	TON3H[7:0]							
Reset	0xFF							
Access Type	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON3H	7:0	High byte of 18-bit TON setting for channel 3.

### TON3L REG (0xA)

On-time setting for channel 3 with 50ns resolution, middle byte.

BIT	7	6	5	4	3	2	1	0
Field	TON3L[7:0]							
Reset	0xFF							
Access Type	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON3L	7:0	Middle byte of 18-bit TON setting for channel 3.

### TON4H REG (0xB)

On-time setting for channel 4 with 50ns resolution, high byte.

BIT	7	6	5	4	3	2	1	0
Field	TON4H[7:0]							
Reset	0xFF							
Access Type	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON4H	7:0	High byte of 18-bit TON setting for channel 4.

### TON4L REG (0xC)

On-time setting for channel 4 with 50ns resolution, middle byte.

BIT	7	6	5	4	3	2	1	0
Field	TON4L[7:0]							
Reset	0xFF							
Access Type	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON4L	7:0	Middle byte of 18-bit TON setting for channel 4.

#### TON1\_4LSB\_REG (0xD)

LSBs of on-time setting for all channels with 50ns resolution.

BIT	7	6	5	4	3	2	1	0
Field	TON4LSB[1:0]			TON3LSB[1:0]			TON2LSB[1:0]	
Reset	0b11			0b11			0b11	
Access Type	Write, Read			Write, Read			Write, Read	

BITFIELD	BITS	DESCRIPTION
TON4LSB	7:6	2 least significant bits of 18-bit TON setting for channel 4.
TON3LSB	5:4	2 least significant bits of 18-bit TON setting for channel 3.
TON2LSB	3:2	2 least significant bits of 18-bit TON setting for channel 2.
TON1LSB	1:0	2 least significant bits of 18-bit TON setting for channel 1.

#### TON5H\_REG (0xE)

BIT	7	6	5	4	3	2	1	0
Field	TON5H[7:0]							
Reset	0xFF							
Access Type	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON5H	7:0	High byte of 18-bit TON setting for channel 5.

#### TON5L\_REG (0xF)

BIT	7	6	5	4	3	2	1	0
Field	TON5L[7:0]							
Reset	0xFF							

Access Type	Write, Read							
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BITFIELD	BITS	DESCRIPTION
TON5L	7:0	Middle byte of 18-bit TON setting for channel 5.

**TON6H REG (0x10)**

BIT	7	6	5	4	3	2	1	0
Field	TON6H[7:0]							
Reset	0xFF							
Access Type	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON6H	7:0	High byte of 18-bit TON setting for channel 6.

**TON6L REG (0x11)**

BIT	7	6	5	4	3	2	1	0
Field	TON6L[7:0]							
Reset	0xFF							
Access Type	Write, Read							

BITFIELD	BITS	DESCRIPTION
TON6L	7:0	Middle byte of 18-bit TON setting for channel 6.

**TON5 6LSB REG (0x12)**

BIT	7	6	5	4	3	2	1	0
Field	—	—	—	TON_ALL	TON6LSB[1:0]			TON5LSB[1:0]
Reset	—	—	—	0b0	0b11			0b11
Access Type	—	—	—	Write, Read	Write, Read			Write, Read

BITFIELD	BITS	DESCRIPTION
TON_ALL	4	When 1, this bit causes the TON1 value to be used for all active channels.
TON6LSB	3:2	2 least significant bits of 18-bit TON setting for channel 6.
TON5LSB	1:0	2 least significant bits of 18-bit TON setting for channel 5.

**SETTING REG (0x13)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	MM_MODE	FPWM[2:0]			SS_OFF	SSL	SLDET[1:0]	
<b>Reset</b>	0b0	0b001			0b0	0b0	0b00	
<b>Access Type</b>	Write, Read	Write, Read			Write, Read	Write, Read	Write, Read	

BITFIELD	BITS	DESCRIPTION	DECODE																																				
MM_MODE	7	This bit determines the device behavior when either a TON or a current mismatch is detected on any of the active channels.	0x0: Assert FLT_B output low. 0x1: Assert FLT_B output low and turn off boost converter and OUT1-6 current sinks.																																				
FPWM	6:4	<p>These bits set the PWM frequency in internal PWM mode.</p> <table border="1"> <thead> <tr> <th>FPWM2</th> <th>FPWM1</th> <th>FPWM0</th> <th>PWM FREQUENCY (Hz)</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>0</td> <td>0</td> <td>153</td> </tr> <tr> <td>0</td> <td>0</td> <td>1</td> <td>203</td> </tr> <tr> <td>0</td> <td>1</td> <td>0</td> <td>305</td> </tr> <tr> <td>0</td> <td>1</td> <td>1</td> <td>610</td> </tr> <tr> <td>1</td> <td>0</td> <td>0</td> <td>980</td> </tr> <tr> <td>1</td> <td>0</td> <td>1</td> <td>1220</td> </tr> <tr> <td>1</td> <td>1</td> <td>0</td> <td>1401</td> </tr> <tr> <td>1</td> <td>1</td> <td>1</td> <td>1634</td> </tr> </tbody> </table>	FPWM2	FPWM1	FPWM0	PWM FREQUENCY (Hz)	0	0	0	153	0	0	1	203	0	1	0	305	0	1	1	610	1	0	0	980	1	0	1	1220	1	1	0	1401	1	1	1	1634	
FPWM2	FPWM1	FPWM0	PWM FREQUENCY (Hz)																																				
0	0	0	153																																				
0	0	1	203																																				
0	1	0	305																																				
0	1	1	610																																				
1	0	0	980																																				
1	0	1	1220																																				
1	1	0	1401																																				
1	1	1	1634																																				
SS_OFF	3	When 1, spread-spectrum switching is disabled. Default value is 0.																																					
SSL	2	When spread spectrum is enabled, the SSL bit sets the level of spread. When 0, the spread is nominally $\pm 6\%$ . When 1, the spread is $\pm 3\%$ . When changing the percentage, disable spread spectrum using the SS_OFF bit first. Then, change the value of SSL. Finally, reenable spread spectrum using SS_OFF.																																					
SLDET	1:0	Shorted-LED threshold Settings.																																					

BITFIELD	BITS	DESCRIPTION		DECODE
		00 8V		
		01 3V		
		10 6V		
		11 8V		

### DISABLE REG (0x14)

Channel-disable bits.

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	—	SLDET_DIS	CP_DIS	DIS6	DIS5	DIS4	DIS3	DIS2
<b>Reset</b>	—	0x0	0b0	0b0	0b0	0b0	0b0	0b0
<b>Access Type</b>	—	Write, Read						

BITFIELD	BITS	DESCRIPTION
SLDET_DIS	6	When 1 the shorted-LED detection is disabled.
CP_DIS	5	When 1, this bit disables the internal charge pump which drives the NGATE pin. Set to 1 when an external series switch is not used. Setting CP_DIS to zero during operation will cause complete shutdown of the device and is not recommended.
DIS6	4	Set bit to 1 to disable OUT6. This must be done before ENA is written to 1.
DIS5	3	Set bit to 1 to disable OUT5. This must be done before ENA is written to 1.
DIS4	2	Set bit to 1 to disable OUT4. This must be done before ENA is written to 1.
DIS3	1	Set bit to 1 to disable OUT3. This must be done before ENA is written to 1.
DIS2	0	Set bit to 1 to disable OUT2. This must be done before ENA is written to 1.

### FADING REG (0x15)

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	—	—	—	FADE_GAIN	FADE_IN_OUT	TDIM[2:0]		
<b>Reset</b>	—	—	—	0b0	0b0	0b000		
<b>Access Type</b>	—	—	—	Write, Read	Write, Read	Write, Read		

BITFIELD	BITS	DESCRIPTION	DECODE
FADE_GAIN	4	When this bit is set to 1, the fade-in-out function has a gain of 12.5%, otherwise 6.25%.	
FADE_IN_OUT	3	When this bit is set to 1, the fade-in-out function for the LED dimming is enabled.	
TDIM	2:0	Sets the fading update time interval according to $2^{\text{TDIM}}$ . TDIM can be between 0 and 5. When set to 0, fading is updated on every dimming cycle.	0x0: 1 0x1: 2 0x2: 4 0x3: 8 0x4: 16 0x5: 32 0x6: N/A 0x7: N/A

### LO\_DIM (0x16)

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	—	—	LO_DIM6	LO_DIM5	LO_DIM4	LO_DIM3	LO_DIM2	LO_DIM1
<b>Reset</b>	—	—	0b0	0b0	0b0	0b0	0b0	0b0
<b>Access Type</b>	—	—	Read Only					

BITFIELD	BITS	DESCRIPTION
LO_DIM6	5	When 1, indicates channel 6 is in low-dim mode.
LO_DIM5	4	When 1, indicates channel 5 is in low-dim mode.
LO_DIM4	3	When 1, indicates channel 4 is in low-dim mode.
LO_DIM3	2	When 1, indicates channel 3 is in low-dim mode.
LO_DIM2	1	When 1, indicates channel 2 is in low-dim mode.
LO_DIM1	0	When 1, indicates channel 1 is in low-dim mode.

### OPEN\_REG (0x17)

Open-string diagnostics.

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	—	—	OUT6O	OUT5O	OUT4O	OUT3O	OUT2O	OUT1O
<b>Reset</b>	—	—	0b0	0b0	0b0	0b0	0b0	0b0
<b>Access Type</b>	—	—	Read Clears All					

BITFIELD	BITS	DESCRIPTION
OUT6O	5	If 1, an open is detected on channel 6.
OUT5O	4	If 1, an open is detected on channel 5.
OUT4O	3	If 1, an open is detected on channel 4.
OUT3O	2	If 1, an open is detected on channel 3.
OUT2O	1	If 1, an open is detected on channel 2.
OUT1O	0	If 1, an open is detected on channel 1.

### SHORTGND REG (0x18)

Short-to-ground diagnostics.

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	–	–	OUT6SG	OUT5SG	OUT4SG	OUT3SG	OUT2SG	OUT1SG
<b>Reset</b>	–	–	0b0	0b0	0b0	0b0	0b0	0b0
<b>Access Type</b>	–	–	Read Clears All					

BITFIELD	BITS	DESCRIPTION
OUT6SG	5	If 1, a short-to-ground is detected on channel 6 at startup.
OUT5SG	4	If 1, a short-to-ground is detected on channel 5 at startup.
OUT4SG	3	If 1, a short-to-ground is detected on channel 4 at startup.
OUT3SG	2	If 1, a short-to-ground is detected on channel 3 at startup.
OUT2SG	1	If 1, a short-to-ground is detected on channel 2 at startup.
OUT1SG	0	If 1, a short-to-ground is detected on channel 1 at startup.

### SHORTED LED REG (0x19)

Shorted-LED diagnostics.

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	–	–	OUT6SL	OUT5SL	OUT4SL	OUT3SL	OUT2SL	OUT1SL
<b>Reset</b>	–	–	0b0	0b0	0b0	0b0	0b0	0b0

Access Type	-	-	Read Clears All					
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BITFIELD	BITS	DESCRIPTION
OUT6SL	5	If 1, a shorted-LED condition is detected on channel 6.
OUT5SL	4	If 1, a shorted-LED condition is detected on channel 5.
OUT4SL	3	If 1, a shorted-LED condition is detected on channel 4.
OUT3SL	2	If 1, a shorted-LED condition is detected on channel 3.
OUT2SL	1	If 1, a shorted-LED condition is detected on channel 2.
OUT1SL	0	If 1, a shorted-LED condition is detected on channel 1.

### MASK1 REG (0x1A)

Mask register for the FLTB pin.

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	-	-	-	BSTUVMASK	OMASK	SGMASK	OTWMASK	SLMASK
<b>Reset</b>	-	-	-	0b0	0b0	0b0	0b1	0b0
<b>Access Type</b>	-	-	-	Write, Read				

BITFIELD	BITS	DESCRIPTION
BSTUVMASK	4	When 1, a boost undervoltage fault does not cause the FLTB pin to assert low.
OMASK	3	When 1, an open-LED fault does not cause the FLTB pin to assert low.
SGMASK	2	When 1, a short-to-ground LED fault does not cause the FLTB pin to assert low.
OTWMASK	1	When 1, an overtemperature warning does not cause the FLTB pin to assert low.
SLMASK	0	When 1, a shorted-LED fault does not cause the FLTB pin to assert low.

### MASK2 REG (0x1B)

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	TON_MM_MASK	PEC_ERRMASK	BATT_UVMASK	I_MM_MASK	-	-	-	-
<b>Reset</b>	0x0	0x0	0x0	0x0	-	-	-	-

Access Type	Write, Read	Write, Read	Write, Read	Write, Read	-	-	-	-
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BITFIELD	BITS	DESCRIPTION
TON_MM_MASK	7	When 1, a TON mismatch does not cause FLTB to assert low.
PEC_ERRMASK	6	When 1, an interface parity error does not cause FLTB to assert low.
BATT_UVMASK	5	When 1, an undervoltage on BATT does not cause FLTB to assert low.
I_MM_MASK	4	When 1, an OUT_ current mismatch does not cause FLTB to assert low.

### DIAG1\_REG (0x1C)

Boost state, overtemperature-warning/shutdown diagnostics.

BIT	7	6	5	4	3	2	1	0
Field	RTOOR	ISETOOR	IREFOOR	BSTUV	BSTOV	HW_RST	OTW	OT
Reset	0b0	0x0	0b0	0b0	0b0	0b1	0b0	0b0
Access Type	Read Clears All	Read Only	Read Clears All					

BITFIELD	BITS	DESCRIPTION
RTOOR	7	This bit is set to 1 if the resistor on the RT pin is out of the expected range. When this happens, the device cannot operate.
ISETOOR	6	When 1, this bit indicates a short to ground on ISET. In this condition, the device does not operate. Power must be recycled to restart the device.
IREFOOR	5	When 1, this bit indicates that the IREF current is out of range. This is more than likely due to an incorrect resistor value on ISET. In this condition, the IC stops operation.
BSTUV	4	If 1, an undervoltage is detected on the boost output, and the boost is disabled.
BSTOV	3	If 1, the boost converter is at its overvoltage limit.
HW_RST	2	If 1, the device has just emerged from a hardware reset (power-up). This bit is reset after the first read from this register.
OTW	1	If 1, the junction temperature of the device is over $T_{WARN}$ , or the temperature foldback circuit has reached the temperature $T_1$ .
OT	0	If 1, the junction temperature of the device has exceeded $T_{SHDN}$ or the TEMP input reached the level which shuts off the LED currents.

**DIAG2 REG (0x1D)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	V18OOR	PEC_ERR	BATT_UV	CLK_ERR	V5OOR	VREFOOR	NV_FLT	ISNS_SD
<b>Reset</b>	0b0	0b0	0b0	0b0	0b0	0b0	0x0	0b0
<b>Access Type</b>	Read Clears All	Read Clears All	Read Clears All	Read Only	Read Clears All	Read Clears All	Read Only	Read Clears All

BITFIELD	BITS	DESCRIPTION
V18OOR	7	When 1, this bit indicates that the 1.8V regulator output is not in range.
PEC_ERR	6	When 1, this bit indicates an I <sup>2</sup> C communication parity error.
BATT_UV	5	When 1, this bit indicates that the BATT input is below the V <sub>BATT_LVF</sub> level.
CLK_ERR	4	When this bit is 1, the internal clock has been inactive for 1μs or is out-of-range. When this fault occurs, the FLTB pin asserts low and the local host should disable the device using the EN pin. This fault can only be cleared by power-on reset (POR).
V5OOR	3	When 1, this bit indicates that the V5 supply is out of range and that the device was shut down as a consequence.
VREFOOR	2	When 1, this bit indicates a mismatch between bandgap references.
NV_FLT	1	When 1, this bit indicates a fault in the internal device nonvolatile memory. If this fault occurs, FLTB is asserted low and the device does not operate.
ISNS_SD	0	When 1, this bit indicates that the voltage between the BATT and SENSE pins exceeded 200mV and the boost converter was disabled unless DIS_ISNS_SD was set to 1.

**I\_MISMATCH (0x1E)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	–	–	I_MM6	I_MM5	I_MM4	I_MM3	I_MM2	I_MM1
<b>Reset</b>	–	–	0b0	0b0	0b0	0b0	0b0	0b0
<b>Access Type</b>	–	–	Read Clears All					

BITFIELD	BITS	DESCRIPTION
I_MM6	5	When 1, this bit indicates that the measured current in channel 6 does not match the iset[6:0] setting.

BITFIELD	BITS	DESCRIPTION
I_MM5	4	When 1, this bit indicates that the measured current in channel 5 does not match the iset[6:0] setting.
I_MM4	3	When 1, this bit indicates that the measured current in channel 4 does not match the iset[6:0] setting.
I_MM3	2	When 1, this bit indicates that the measured current in channel 3 does not match the iset[6:0] setting.
I_MM2	1	When 1, this bit indicates that the measured current in channel 2 does not match the iset[6:0] setting.
I_MM1	0	When 1, this bit indicates that the measured current in channel 1 does not match the iset[6:0] setting.

**TON MISMATCH (0x1F)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	–	–	TON6_MM	TON5_MM	TON4_MM	TON3_MM	TON2_MM	TON1_MM
<b>Reset</b>	–	–	0b0	0b0	0b0	0b0	0b0	0b0
<b>Access Type</b>	–	–	Read Only					

BITFIELD	BITS	DESCRIPTION
TON6_MM	5	When 1, this bit indicates a TON mismatch on OUT6.
TON5_MM	4	When 1, this bit indicates a TON mismatch on OUT5.
TON4_MM	3	When 1, this bit indicates a TON mismatch on OUT4.
TON3_MM	2	When 1, this bit indicates a TON mismatch on OUT3.
TON2_MM	1	When 1, this bit indicates a TON mismatch on OUT2.
TON1_MM	0	When 1, this bit indicates a TON mismatch on OUT1.

**MM DIS (0x20)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	I_MM_DIS	TON_MM_DIS	TON6_MM_DIS	TON5_MM_DIS	TON4_MM_DIS	TON3_MM_DIS	TON2_MM_DIS	TON1_MM_DIS
<b>Reset</b>	0b0	0b0	0b0	0b0	0b0	0b0	0b0	0b0

<b>Access Type</b>	Write, Read							
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BITFIELD	BITS	DESCRIPTION
I_MM_DIS	7	When 1, this bit disables the current mismatch check.
TON_MM_DIS	6	When 1, this bit disables the TON mismatch check on all active channels.
TON6_MM_DIS	5	When 1, this bit disables the TON mismatch check on OUT6.
TON5_MM_DIS	4	When 1, this bit disables the TON mismatch check on OUT5.
TON4_MM_DIS	3	When 1, this bit disables the TON mismatch check on OUT4.
TON3_MM_DIS	2	When 1, this bit disables the TON mismatch check on OUT3.
TON2_MM_DIS	1	When 1, this bit disables the TON mismatch check on OUT2.
TON1_MM_DIS	0	When 1, this bit disables the TON mismatch check on OUT1.

#### VBSTMON (0x21)

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	vbstmon[7:0]							
<b>Reset</b>	0x00							
<b>Access Type</b>	Read Only							

BITFIELD	BITS	DESCRIPTION
vbstmon	7:0	BSTMON voltage measurement from internal ADC.

#### IOUT1 (0x22)

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	iout1[7:0]							
<b>Reset</b>	0x00							
<b>Access Type</b>	Read Only							

BITFIELD	BITS	DESCRIPTION
iout1	7:0	OUT1 current measurement from internal ADC.

**IOUT2 (0x23)**

BIT	7	6	5	4	3	2	1	0
Field	iout2[7:0]							
Reset	0x00							
Access Type	Read Only							

BITFIELD	BITS	DESCRIPTION
iout2	7:0	OUT2 current measurement from internal ADC.

**IOUT3 (0x24)**

BIT	7	6	5	4	3	2	1	0
Field	iout3[7:0]							
Reset	0x00							
Access Type	Read Only							

BITFIELD	BITS	DESCRIPTION
iout3	7:0	OUT3 current measurement from internal ADC.

**IOUT4 (0x25)**

BIT	7	6	5	4	3	2	1	0
Field	iout4[7:0]							
Reset	0x00							
Access Type	Read Only							

BITFIELD	BITS	DESCRIPTION
iout4	7:0	OUT4 current measurement from internal ADC.

**IOUT5 (0x26)**

BIT	7	6	5	4	3	2	1	0
Field	iout5[7:0]							

Reset	0x00							
Access Type	Read Only							

BITFIELD	BITS	DESCRIPTION
iout5	7:0	OUT5 current measurement from internal ADC.

#### IOUT6 (0x27)

BIT	7	6	5	4	3	2	1	0
Field	iout6[7:0]							
Reset	0x00							
Access Type	Read Only							

BITFIELD	BITS	DESCRIPTION
iout6	7:0	OUT6 current measurement from internal ADC.

#### VSENSE (0x28)

BIT	7	6	5	4	3	2	1	0
Field	vsense[7:0]							
Reset	0x00							
Access Type	Read Only							

BITFIELD	BITS	DESCRIPTION
vsense	7:0	ADC result of conversion of voltage between BATT and SENSE pins.

#### DIM\_TON\_HI (0x29)

BIT	7	6	5	4	3	2	1	0
Field	dim_ton_hi[7:0]							
Reset	0x00							
Access Type	Read Only							

BITFIELD	BITS	DESCRIPTION
dim_ton_hi	7:0	High byte of measured on-time value at DIM pin in units of 50ns. This value is 0 when internal dimming is used.

**DIM\_TON\_MID (0x2A)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	dim_ton_mid[7:0]							
<b>Reset</b>	0x00							
<b>Access Type</b>	Read Only							

BITFIELD	BITS	DESCRIPTION
dim_ton_mid	7:0	Middle byte of measured on-time value at DIM pin in units of 50ns. This value is 0 when internal dimming is used.

**DIM\_TON\_LO (0x2B)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	–	–	–	–	–	–	dim_ton_lo[1:0]	
<b>Reset</b>	–	–	–	–	–	–	0b00	
<b>Access Type</b>	–	–	–	–	–	–	Read Only	

BITFIELD	BITS	DESCRIPTION
dim_ton_lo	1:0	Least-significant bits of measured on-time value at DIM pin in units of 50ns. This value is 0 when internal dimming is used.

**DIM\_F\_HI (0x2C)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	dim_f_hi[7:0]							
<b>Reset</b>	0x00							
<b>Access Type</b>	Read Only							

BITFIELD	BITS	DESCRIPTION
dim_f_hi	7:0	High byte of measured frequency value at DIM pin in units of 50ns. At 100% and 0% brightness, the frequency read is approximately 80Hz. The value is 0 when internal dimming is used.

**DIM\_F\_MID (0x2D)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	dim_f_mid[7:0]							
<b>Reset</b>	0x00							
<b>Access Type</b>	Read Only							

BITFIELD	BITS	DESCRIPTION
dim_f_mid	7:0	Middle byte of measured frequency value at DIM pin in units of 50ns. At 100% and 0% brightness, the frequency read is approximately 80Hz. The value is 0 when internal dimming is used.

**DIM\_F\_LO (0x2E)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	—	—	—	—	—	—	dim_f_lo[1:0]	
<b>Reset</b>	—	—	—	—	—	—	0b00	
<b>Access Type</b>	—	—	—	—	—	—	Read Only	

BITFIELD	BITS	DESCRIPTION
dim_f_lo	1:0	Least-significant bits of measured frequency value at DIM pin in units of 50ns. At 100% and 0% brightness, the frequency read is approximately 80Hz. The value is 0 when internal dimming is used.

## Applications Information

### Power-Circuit Design

First select a converter topology based on whether the total converter output voltage (LED string forward voltage + OUT\_headroom) is higher than the maximum input voltage, in which case the boost topology can be used. Otherwise, select the SEPIC configuration. Determine the total output current needed to drive the LED strings ( $I_{LED}$ ) using the following equation:

$$I_{LED} = I_{STRING} \times N_{STRING}$$

where  $I_{STRING}$  is the LED current per string in amperes and  $N_{STRING}$  is the number of strings used. Calculate the maximum duty cycle ( $D_{MAX}$ ) using the following equations:

#### Boost Configuration:

$$D_{MAX} = \frac{(V_{LED} + V_{D1} - V_{IN\_MIN})}{(V_{LED} + V_{D1} - V_{DS} - 0.44)}$$

#### SEPIC Configuration:

$$D_{MAX} = \frac{(V_{LED} + V_{D1})}{(V_{IN\_MIN} - V_{DS} - 0.44 + V_{LED} + V_{D1})}$$

where  $V_{D1}$  is the forward drop of the rectifier diode in volts (approximately 0.6V),  $V_{IN\_MIN}$  is the minimum input supply voltage in volts,  $V_{DS}$  is the drain-to-source voltage of the external MOSFET in volts when it is on, and 0.44V is the peak current-sense voltage in the high-current setting. Initially, use an approximate value of 0.2V for  $V_{DS}$  to calculate  $D_{MAX}$ . Calculate a more accurate value of  $D_{MAX}$  after the power MOSFET is selected based on the maximum inductor current.

#### Boost Configuration

The average inductor current varies with the input voltage, and the maximum average current occurs at the lowest input voltage. For the boost converter, the average inductor current is equal to the input current. Select the maximum desired peak-to-peak ripple on the inductor current ( $\Delta I_L$ ). The recommended peak-to-peak ripple is 60% of the average inductor current.

Use the following equations to calculate the maximum average inductor current ( $IL_{AVG}$ ) and peak inductor current ( $IL_P$ ) in amperes.

$$IL_{AVG} = \frac{I_{LED}}{1 - D_{MAX}}$$

Allowing the peak-to-peak inductor ripple  $\Delta I_L$  to be  $\pm 30\%$  of the average inductor current:

$$\Delta I_L = IL_{AVG} \times 0.3 \times 2$$

and

$$IL_P = IL_{AVG} + \frac{\Delta I_L}{2}$$

Calculate the minimum inductance value ( $L_{MIN}$ ), in henries with the inductor-current ripple set to the maximum value.

$$L_{MIN} = \frac{(V_{IN\_MIN} - V_{DS} - 0.44) \times D_{MAX}}{f_{SW} \times \Delta I_L}$$

where 0.44V is the peak current-sense voltage (with  $bl\_ilim$  set to 0; if  $bl\_ilim$  is set to 1, use 0.325V in this equation). Choose an inductor that has a minimum inductance greater than the calculated  $L_{MIN}$  and a current rating greater than  $IL_P$ . The recommended saturation current limit of the selected inductor is 10% higher than the inductor peak current for the boost configuration.

#### SEPIC Configuration

Power-circuit design for the SEPIC configuration is very similar to a boost design. For SEPIC, the output is referenced to ground and the inductor is split into two parts (see the [Typical Application Circuit](#)). One of the inductors ( $L2$ ) has the LED

current as the average current, and the other inductor (L1) has the input current as its average current. Use the following equations to calculate the average inductor currents ( $IL1_{AVG}$ ,  $IL2_{AVG}$ ) and peak inductor currents ( $IL1_P$ ,  $IL2_P$ ) in amperes:

$$IL1_{AVG} = \frac{I_{LED} \times D_{MAX} \times 1.1}{1 - D_{MAX}}$$

The factor 1.1 provides a 10% margin to account for the converter losses:

$$IL2_{AVG} = I_{LED}$$

Assuming the peak-to-peak inductor ripple  $\Delta I_L$  is  $\pm 30\%$  of the average inductor current:

$$\Delta I_{L1} = IL1_{AVG} \times 0.3 \times 2$$

and

$$IL1_P = IL1_{AVG} + \frac{\Delta I_{L1}}{2}$$

$$\Delta I_{L2} = IL2_{AVG} \times 0.3 \times 2$$

and

$$IL2_P = IL2_{AVG} + \frac{\Delta I_{L2}}{2}$$

Calculate the minimum inductance values  $L1_{MIN}$  and  $L2_{MIN}$  in henries with the inductor current ripples set to the maximum value as follows:

$$L1_{MIN} = \frac{(V_{IN\_MIN} - V_{DS} - 0.44) \times D_{MAX}}{f_{SW} \times \Delta I_{L1}}$$

$$L2_{MIN} = \frac{(V_{IN\_MIN} - V_{DS} - 0.44) \times D_{MAX}}{f_{SW} \times \Delta I_{L2}}$$

where 0.44V is the peak current-sense voltage. Choose inductors that have a minimum inductance greater than the calculated  $L1_{MIN}$  and  $L2_{MIN}$ , and current ratings greater than  $IL1_P$  and  $IL2_P$ , respectively. The recommended saturation current limit of the selected inductor is 10% higher than the inductor peak current.

To simplify further calculations, consider L1 and L2 as a single inductor with L1/L2 connected in parallel. The combined inductance value and current is calculated as follows:

$$L_{MIN} = \frac{L1_{MIN} \times L2_{MIN}}{L1_{MIN} + L2_{MIN}}$$

and

$$IL_{AVG} = IL1_{AVG} + IL2_{AVG}$$

where  $IL_{AVG}$  represents the total average current through both the inductors connected together for SEPIC configuration. Use these values in the calculations for the SEPIC configuration in the following sections. Select coupling capacitor CS so that its peak-to-peak ripple is less than 2% of the minimum input supply voltage. This ensures that the second-order effects created by the series resonant circuit comprising L1, CS, and L2 do not affect the operation of the converter. Use the following equation to calculate the minimum value of CS:

$$CS \geq \frac{I_{LED} \times D_{MAX}}{V_{IN\_MIN} \times 0.02 \times f_{SW}}$$

where CS is the minimum value of the coupling capacitor in farads,  $I_{LED}$  is the LED current in amperes, and the factor 0.02 reflects the desired 2% ripple.

### Current-Sense Resistor and Slope Compensation

The MAX25561 backlight controller generates a current ramp for slope compensation. This ramp current is synchronized to the switching frequency, starting from zero at the beginning of every clock cycle and rising linearly to reach 50 $\mu$ A at the end of the clock cycle. The slope-compensating resistor ( $R_{SC}$ ) is connected between the CSP input and the source of the external MOSFET. This adds a programmable ramp voltage to the CSP input voltage to provide slope compensation.

Use the following equations to calculate the value of slope-compensation resistance (R<sub>SC</sub>):

**Boost Configuration:**

$$R_{SC} = \frac{(V_{LED} - 2 \times V_{IN\_MIN}) \times R_{CS} \times 3}{L_{MIN} \times 50\mu A \times f_{SW} \times 4}$$

**SEPIC and Coupled-Inductor Configurations:**

$$R_{SC} = \frac{(V_{LED} - V_{IN\_MIN}) \times R_{CS} \times 3}{L_{MIN} \times 50\mu A \times f_{SW} \times 4}$$

where V<sub>LED</sub> and V<sub>IN\_MIN</sub> are in volts, R<sub>SC</sub> and R<sub>CS</sub> are in ohms, L<sub>MIN</sub> is in henries, and f<sub>SW</sub> is in hertz. The value of the switch current-sense resistor (R<sub>CS</sub>) can be calculated as follows:

**Boost Configuration:**

$$R_{CS} = \frac{4 \times L_{MIN} \times f_{SW} \times V_{CS\_MAX} \times 0.9}{I_{LP} \times 4 \times L_{MIN} \times f_{SW} + D_{MAX} \times (V_{LED} - 2 \times V_{IN\_MIN}) \times 3}$$

**SEPIC and Coupled-Inductor Configurations:**

$$R_{CS} = \frac{4 \times L_{MIN} \times f_{SW} \times V_{CS\_MAX} \times 0.9}{I_{LP} \times 4 \times L_{MIN} \times f_{SW} + D_{MAX} \times (V_{LED} - V_{IN\_MIN}) \times 3}$$

where V<sub>CS\_MAX</sub> is the minimum value of the peak current-sense threshold or 0.38V with bl\_ilim = 0 and 0.275V when bl\_ilim is set to 1. The current-sense threshold also includes the slope-compensation component. The minimum current-sense threshold is multiplied by 0.9 to take tolerances into account.

**Output Capacitor Selection**

In both converter topologies, the output capacitor supplies the load current when the main switch is on. The function of the output capacitor is to reduce the converter output ripple to acceptable levels. The entire output-voltage ripple appears across the constant-current sink outputs because the LED string voltages are stable due to their constant current. For the MAX25561, limit the peak-to-peak output-voltage ripple to 250mV in order to get stable output current.

The ESR, ESL, and bulk capacitance of the output capacitor contribute to the output ripple. In most applications, using low-ESR ceramic capacitors can dramatically reduce the output ESR and ESL effects, connecting multiple ceramic capacitors in parallel to achieve the required bulk capacitance. To minimize audible noise during PWM dimming however, it may be desirable to limit the use of ceramic capacitors on the boost output. In such cases, an additional electrolytic or tantalum capacitor can provide the majority of the bulk capacitance.

**External Switching MOSFET Selection**

The external switching MOSFET should have a voltage rating sufficient to withstand the maximum boost output voltage together with the rectifier diode drop and any possible overshoot due to ringing caused by parasitic inductance and capacitance. The recommended MOSFET V<sub>DS</sub> voltage rating is 30% higher than the sum of the maximum output voltage and the rectifier diode drop.

The continuous drain-current rating of the MOSFET (ID), when the case temperature is at the maximum operating ambient temperature, should be greater than that calculated in the following equation:

$$ID_{RMS} = \left( \sqrt{IL_{AVG}^2 \times D_{MAX}} \right) \times 1.3$$

The MOSFET dissipates power due to both switching losses and conduction losses. Use the following equation to calculate the conduction losses in the MOSFET.

$$P_{COND} = IL_{AVG}^2 \times D_{MAX} \times R_{DS(ON)}$$

where R<sub>DS(ON)</sub> is the on-state, drain-to-source resistance of the MOSFET. Use the following equation to calculate the switching losses in the MOSFET:

$$P_{SW} = \frac{IL_{AVG} \times V_{LED}^2 \times C_{GD} \times f_{SW}}{2} \times \left( \frac{1}{I_{GON}} + \frac{1}{I_{GOFF}} \right)$$

where  $I_{GON}$  and  $I_{GOFF}$  are the gate currents of the MOSFET in amperes when it is turned on and turned off, respectively.  $C_{GD}$  is the gate-to-drain MOSFET capacitance in farads.

### Rectifier Diode Selection

Using a Schottky rectifier diode produces less forward drop and puts the least burden on the MOSFET during reverse recovery. A diode with considerable reverse-recovery time increases the MOSFET switching loss. Select a diode with a voltage rating that is 20% higher than the maximum boost-converter output voltage and a current rating greater than:

$$I_D = I_{LAVG} \times (1 - D_{MAX}) \times 1.2$$

### Feedback Compensation

During normal operation, the feedback control loop regulates the minimum  $OUT_{-}$  voltage to fall within the window comparator limits of 0.78V and 1.03V when LED string currents are enabled during PWM dimming. When LED currents are off during PWM dimming, the control loop turns off the converter and stores the previous boost output-voltage value for use during the next on cycle. The switching converter small-signal-transfer function has a right-half plane (RHP) zero in the boost configuration if the inductor current is in continuous-conduction mode. The RHP zero adds a 20dB/decade gain together with a 90° phase lag, which is difficult to compensate.

#### Worst-Case RHP Zero Frequency ( $f_{ZRHP}$ ):

$$f_{ZRHP} = V_{LED} \times \frac{(1 - D_{MAX})^2}{2 \times \pi \times L \times I_{LED}}$$

#### SEPIC and Coupled-Inductor Configurations:

$$f_{ZRHP} = V_{LED} \times \frac{(1 - D_{MAX})^2}{2 \times \pi \times L \times I_{LED} \times D_{MAX}}$$

The standard way to avoid this zero is to roll off the loop gain to 0dB at a frequency of less than 1/5 of the RHP zero frequency with a -20dB/decade slope. The switching converter small-signal transfer function also has an output pole. The effective output impedance, together with the output filter capacitance, determines the output pole frequency ( $f_{P1}$ ) that is calculated as follows:

#### Boost Configuration:

$$f_{P1} = \frac{I_{LED}}{\pi \times V_{LED} \times C_{OUT}}$$

#### SEPIC and Coupled-Inductor Configurations:

$$f_{P1} = I_{LED} \times \frac{D_{MAX}}{\pi \times V_{LED} \times C_{OUT}}$$

Compensation components  $R_{COMP}$  and  $C_{COMP}$  perform two functions.  $C_{COMP}$  introduces a low-frequency pole that presents a -20dB/decade slope to the loop gain.  $R_{COMP}$  flattens the gain of the error amplifier for frequencies above the zero formed by  $R_{COMP}$  and  $C_{COMP}$ . For compensation, this zero is placed at  $f_{P1}$  to provide a -20dB/decade slope for frequencies above  $f_{P1}$  to the combined modulator and compensator response. The value of  $R_{COMP}$  needed to fix the total loop gain at  $f_{P1}$  so the total loop gain crosses 0dB with -20dB/decade slope at 1/5 the RHP zero frequency is calculated as follows:

#### Boost Configuration:

$$R_{COMP} = f_{ZRHP} \times R_{CS} \times I_{LED} \times A_{OVP} / (5 \times f_{P1} \times G_{MCOMP} \times V_{LED} \times (1 - D_{MAX}))$$

#### SEPIC and Coupled-Inductor Buck-Boost Configurations:

$$R_{COMP} = f_{ZRHP} \times R_{CS} \times I_{LED} \times A_{OVP} \times D_{MAX} / (5 \times f_{P1} \times G_{MCOMP} \times V_{LED} \times (1 - D_{MAX}))$$

where:

$R_{COMP}$  = Compensation resistor in  $\Omega$

$A_{OVP}$  = BSTMON resistor-divider gain (a value  $\gg 1$ )

$R_{CS}$  = Current-sense resistor in  $\Omega$

$G_{MCOMP}$  = Transconductance of the error amplifier (600 $\mu$ S)

The value of  $C_{COMP}$  is calculated as follows:

$$C_{COMP} = \frac{1}{2 \times \pi \times f_{Z1} \times R_{COMP}}$$

where  $f_{Z1}$  is the compensation zero placed at 1/5 the crossover frequency, which is, in turn, set at 1/5 the  $f_{ZRHP}$ .

If the output capacitors do not have low ESR, the ESR zero frequency could fall below the 0dB crossover frequency. An additional pole may be required to cancel out this zero placed at the same frequency. This can be added by connecting a capacitor from the COMP pin directly to GND with a value shown as follows:

$$C_{PAR} = G_{MCOMP} \times R_{ESR} \times C_{OUT}$$

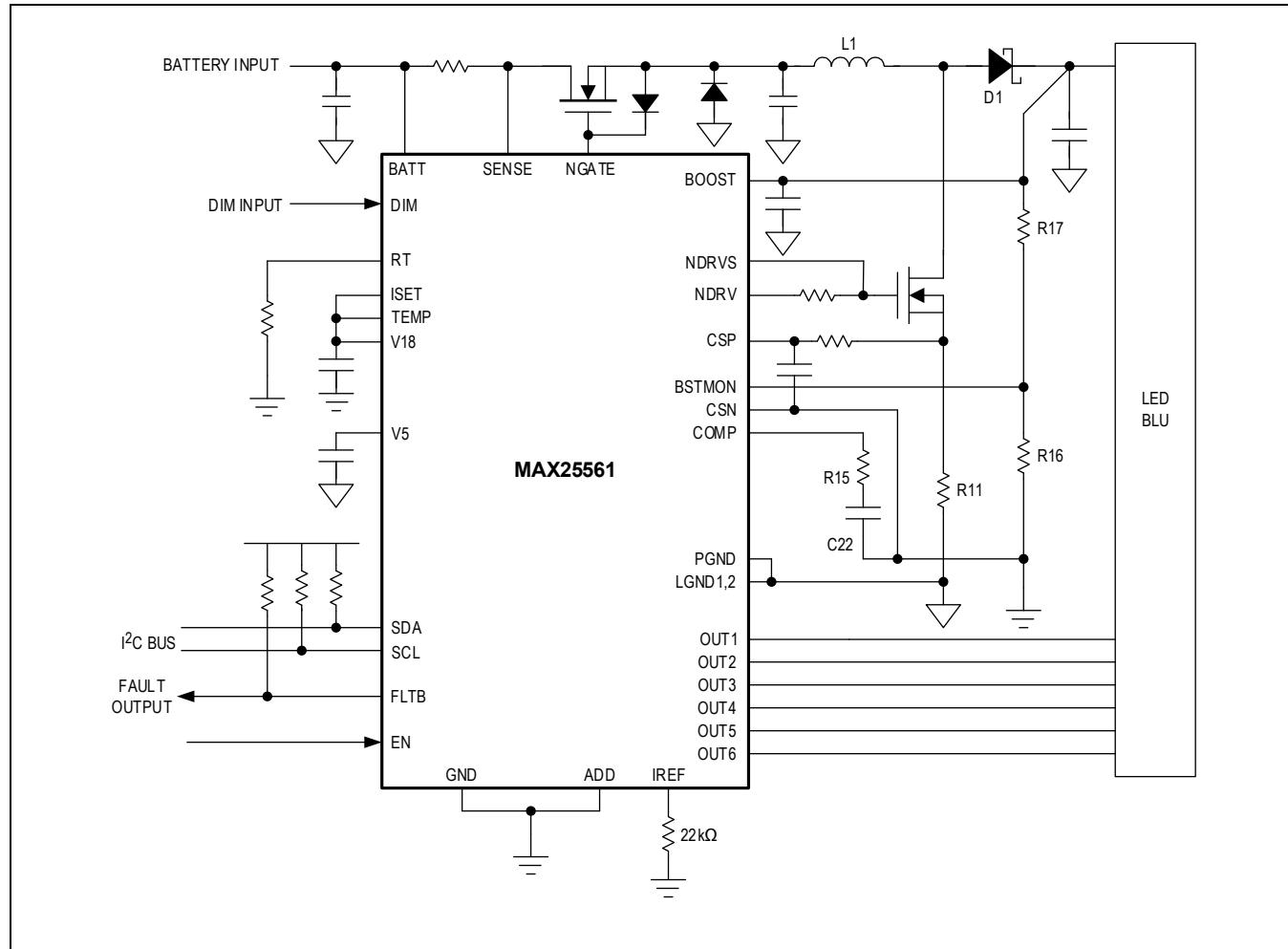
where  $R_{ESR}$  is the capacitor ESR value and  $C_{OUT}$  is the output-capacitor value.

### PCB Layout Considerations

The MAX25561 incorporates a high-frequency switching converter and, as such, careful circuit board layout is required to ensure correct device operation and optimize EMI performance. The switching-converter portion of the circuit contains nodes with very fast voltage transients, which could lead to undesirable effects on the sensitive parts of the circuit. Observe the following guidelines when designing a circuit board for the MAX25561:

1. Make the connections from the sense resistor to the BATT and SENSE pins as short and as wide as possible. This ensures a low-resistance connection, which enhances sensing accuracy.
2. Connect the components related to the following pins as close as possible to the device to avoid noise pickup: ISET, RT, BSTMON, and COMP. Connect their ground terminals to an analog ground plane or directly to the device GND pin. The CSN pin should be connected directly to the ground of the network connected to COMP.
3. Connect the bypass capacitors on V18 as close as possible to the device, and connect the capacitor ground to the nearest GND pin. Connect the GND of the device to the analog ground plane using a via placed close to GND.
4. Connect the bypass capacitors on V5 as close as possible to the device, and connect the capacitor ground to power GND.
5. Have a power-ground plane for the switching-converter power circuit under the power components (i.e., input filter capacitor, output filter capacitor, inductor, MOSFET, rectifier diode, and current-sense resistor). Connect PGND to the power-ground plane closest to PGND. Connect all other ground connections to the power ground plane using vias placed close to the terminals.
6. There are two loops in the power circuit that carry high-frequency switching currents. One loop is when the MOSFET is on (from the input filter capacitor positive terminal, through the inductor, the internal MOSFET, and the current-sense resistor, to the input capacitor negative terminal). The other loop is when the MOSFET is off (from the input capacitor positive terminal, through the inductor, the rectifier diode, and the output filter capacitor, to the input capacitor negative terminal). Analyze these two loops and make the loop areas as small as possible. Wherever possible, have a return path on the power-ground plane for the switching currents on the top-layer copper traces, or through power components. This reduces the loop area considerably and provides a low-inductance path for the switching currents. Reducing the loop area also reduces radiation during switching.
7. Connect the power-ground plane for the constant-current LED-driver portion of the circuit to LEDGND as close as possible to the device. Connect GND to PGND at the same point.
8. Boost output voltage for the LED strings should be taken directly from the output capacitors and not from the boost diode anode.
9. Input and output capacitors need good grounding with wide traces and multiple vias to the ground plane.

## Typical Application Circuit Boost Configuration



## Ordering Information

PART	TEMP RANGE	PACKAGE CODE	PIN-PACKAGE
MAX25561ATJ/V+	-40°C to +125°C	T3255+6C	32-TQFN-EP*
MAX25561ATJ/VY+	-40°C to +125°C	T3255Y+6C	32-TQFN-EP*

/V Denotes an automotive-qualified part.

+ Denotes a lead(Pb)-free/RoHS-compliant package.

\*EP = Exposed pad.

Y = Side-wettable (SW) package.

T Denotes tape-and-reel.

## Chip Information

PROCESS: BiCMOS

## Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	10/23	Initial release	—
1	11/24	Added T3255Y+6C in Package Information and Ordering Information tables	3, 55
2	7/25	Corrected instances of "mF" to "μF", added SLDET_DIS bit in register 0x14, corrected references to Figures 8 and 9.	12, 25, 26, 38