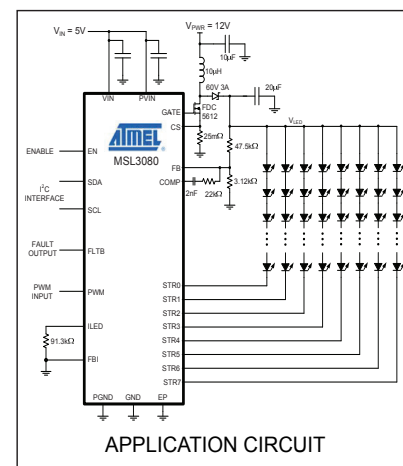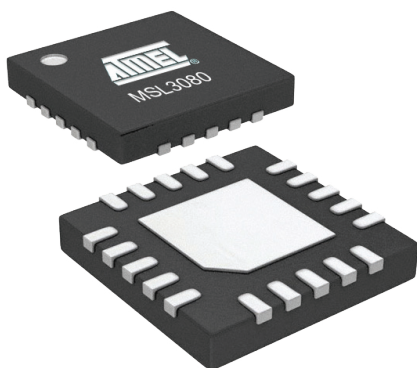# Atmel MSL3080

8 String 60mA LED Drivers
with Integrated Boost Controller

FULL DATASHEET

Features:

- Drives 8 parallel 60mA LED strings at up to 40V LED string voltage
- Integrated boost controller
- Offers true 12-bit LED dimming at 120Hz
- String open circuit and LED short circuit fault detection and automatic shut down
- ±3% current accuracy and current balance
- Single resistor sets current for all LED strings
- External PWM dimming
- Internal PWM dimming control engine
- Single PWM input sets dimming duty cycle and frequency
- Internal PWM dimming (use optional)
- Synchronizes PWM dimming to LCD panel refresh rate
- Frequency multiplier allows PWM dimming at multiples of LCD panel refresh frequency (see Programming Guide)
- 1MHz I²C/SMBus interface; use optional
- Resistor programmable LED short circuit threshold
- Die over-temperature cut-off protection
- -40°C to +85°C operating temperature range
- Lead free, halogen free, RoHS compliant package

APPLICATION CIRCUIT

Description:

The MSL3080 8-channel LED drivers with integrated boost regulator controller offers a complete solution to drive parallel LED strings at up to 40V. The LED current sinks control up to 60mA each for up to 19W of LED power. The MSL3080 has eight current sinks. Parallel connect the current sinks for increased string current. A single resistor sets LED current, with string matching and accuracy within ±3%.

The advanced integrated PWM circuitry allows up to 4095:1 dimming, and offers simple PWM dimming control. External PWM dimming is controlled by a signal at the PWM input, which sets both the PWM duty cycle and frequency of the dimming signals. The internal PWM dimming is controlled by registers accessible through the I²C serial interface.

The MSL3080 feature integrated fault detection circuitry that detects and acts upon string open-circuit and LED short circuit faults, boost regulator over-voltage faults, and die over-temperature faults. A proprietary Efficiency Optimizer maintains sufficient boost regulator output voltage to maintain LED current regulation while minimizing power use. A 1MHz I²C/SMBus serial interface allows optional dimming control, fault inspection and control of driver configuration; for serial interface information see the "**MSL3040/50/60/80/86/87/88 Programming Guide"**.

The MSL3080 IS offered in the 24-pin VQFN lead-free, halogen-free, RoHS compliant package and operate over -40°C to +85°C.
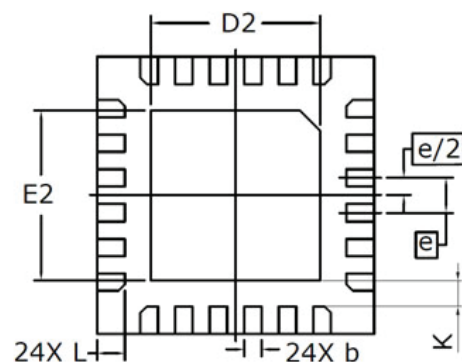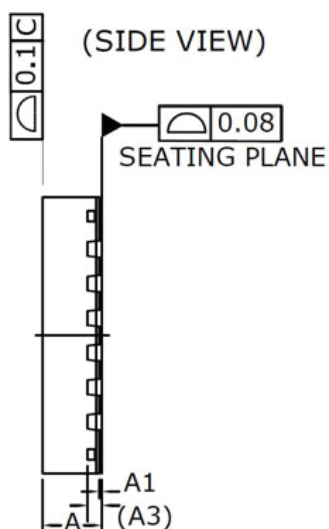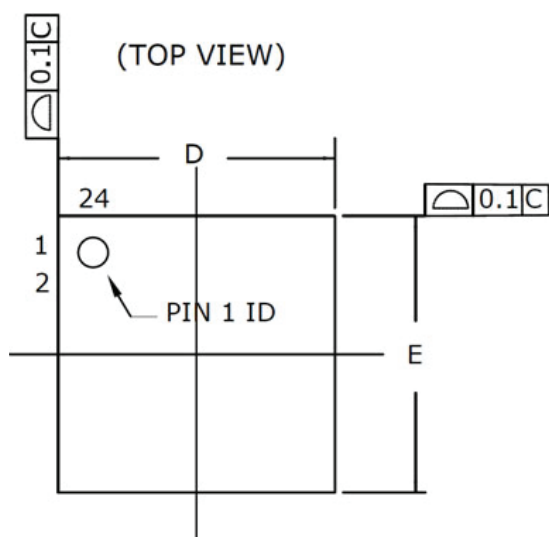
Table of Contents

1.0 Packages and Pin Connections

1.1 24 pin 4 x 4 x 0.75mm VQFN Package

MSL3080
(TOP VIEW)

Pins left side: FB 1, VIN 2, SDA 3, SCL 4, SCTH 5, STR0 6

Pins right side: GATE 18, PGND 17, ILED 16, CGND 15, PWM 14, STR7 13

Pins top: GND 24, COMP 23, CS 22, EN 21, FLTB 20, PVIN 19

Pins bottom: STR1 7, STR2 8, STR3 9, STR4 10, STR5 11, STR6 12

(TOP VIEW)

(SIDE VIEW)

SEATING PLANE

(BOTTOM VIEW)

COMMON DIMENSIONS (UNIT OF MEASURE=MM)

SYMBOL	MIN	NOM	MAX	NOTE
A	-	0.85	0.90	
A1	0.00	-	0.05	
A3		0.203 REF		
b	0.20	0.25	0.30	2
D		4.00 BSC		
D2	2.35	2.45	2.55	
E		4.00 BSC		
E2	2.35	2.45	2.55	
e		0.50 BSC		
L	0.35	0.40	0.45	
K	0.20	-	-	

NOTES:

1. Refer to JEDEC Drawing MO-220 (SAW SINGULATION)

2. Dimension "b" applies to metalized terminal and is measured between 0.15mm and 0.30mm from the terminal tip. If the terminal has the optional radius on the other end of the terminal, the dimension should not be measured in that radius area.

2.0 Pin Descriptions

Table 2.1 Pin Assignments

Name	MSL3080	Pin Description
FB	1	**V_{LED} Voltage Regulator Feedback Input:** Connect a resistive voltage divider from the boost regulator output, V_{LED}, to FB to set the un-optimized boost regulator output voltage. The feedback regulation voltage is 2.5V.
VIN	2	**Power Supply Input:** Power supply input. Apply 4.5V to 5.5V to VIN. Decouple VIN to GND a 1µF or greater capacitor placed close to VIN.
SDA	3	**I²C Serial Data I/O:** SDA is the I²C serial interface data input/output. Connect SDA to VIN when unused. For interface information see the *"MSL3040/50/60/80/86/87/88 Programming Guide"*.
SCL	4	**I²C Serial Clock Input:** SCL is the I²C serial interface clock input. Connect SCL to VIN when unused. For interface information see the *"MSL3040/50/60/80/86/87/88 Programming Guide"*.
SCTH	5	**String Short Circuit Threshold Level Setting Input:** SCTH programs the LED string short-circuit detection threshold. Connect a resistor from SCTH to GND to set the short-circuit threshold level to 4.9V (1kΩ), 5.8V (27kΩ), 6.8V (68kΩ) or 7.6V (330kΩ). A short circuit is detected when the STR*n* voltage is above the threshold while STR*n* is on. See the section *"Setting the LED Short-Circuit Threshold"* on page 17 for information.
STR0	6	**LED String 0 Current Sink:** Connect the cathode end of series LED String 0 to STR0. If not used, connect STR0 to GND.
STR1	7	**LED String 1 Current Sink:** Connect the cathode end of series LED String 1 to STR1. If not used, connect STR1 to GND.
STR2	8	**LED String 2 Current Sink:** Connect the cathode end of series LED String 2 to STR2. If not used, connect STR2 to GND.
STR3	9	**LED String 3 Current Sink:** Connect the cathode end of series LED String 3 to STR3. If not used, connect STR3 to GND.
STR4	10	**LED String 4 Current Sink:** Connect the cathode end of series LED String 4 to STR4. If not used, connect STR4 to GND.
STR5	11	**LED String 5 Current Sink:** Connect the cathode end of series LED String 5 to STR5. If not used, connect STR5 to GND.
STR6	12	**LED String 6 Current Sink:** Connect the cathode end of series LED String 6 to STR6. If not used, connect STR6 to GND.
STR7	13	**LED String 7 Current Sink:** Connect the cathode end of series LED String 7 to STR7. If not used, connect STR7 to GND.
CGND	15	**Connect To Ground:** Connect CGND to GND close to the driver.
PWM	14	**PWM Dimming and Synchronization Input:** Drive PWM with a pulse-width modulated signal with duty cycle of 0% to 100% and frequency of 20Hz to 50kHz to control the duty cycle and the frequency of all LED strings. For serial interface controlled PWM dimming connect PWM to GND and refer to the register definitions section for registers 0x10 through 0x14 in the *"MSL3040/50/60/80/86/87/88 Programming Guide"*.
ILED	16	**Maximum LED Current Control Input:** Connect a resistor from ILED to GND to set the full-scale LED current. See the section *"Setting the LED Current"* on page 17 for more information.
PGND	17	**Power Ground:** Ground of the boost regulator gate driver. Connect PGND to GND, EP and CGND as close to the MSL3080 as possible.
GATE	18	**Gate Drive Output:** Connect GATE to the gate of the boost regulator switching MOSFET
PVIN	19	**Boost Regulator Power Supply Input:** PVIN is the power supply input for the external MOSFET gate driver. Apply 4.5V to 5.5V to PVIN. Decouple PVIN with two 1µF capacitors placed close to PVIN.
FLTB	20	**Fault Output:** FLTB sinks current to GND when a fault is detected. Clear faults by toggling EN low and then high, by cycling input power off and on, or through the I²C serial interface; see the *"MSL3040/50/60/80/86/87/88 Programming Guide"* for information.
EN	21	**Enable Input:** Drive EN high to turn on the device, drive it low to turn it off. For automatic startup connect EN to VIN. Toggle EN low then high to reset FLTB, or reset it through the I2C serial interface.
CS	22	**Boost Regulator Current Sense Input:** Connect the current sense resistor from CS and the MOSFET source to GND to set the boost regulator current limit. The current limit threshold is 100mV. See the section *"Setting the External MOSFET Current Limit"* beginning on page 21 for more
COMP	23	**Boost Regulator Compensation Node:** Connect the compensation network components from COMP to FB to compensate the boost regulator control loop, as shown in the Typical Applications Circuit on page 10. See the section *"Loop Compensation"* beginning on page 21 for more information.
GND	24	**Signal Ground:** Connect GND to EP, PGND and CGND as close to the device as possible.
EP	EP	**Exposed Die-Attach Paddle:** Connect EP to GND, CGND, PGND and to the system ground. EP is the return path for the LED current as well as the primary thermal path to remove heat generated in the MSL3080. Use a large circuit board trace to connect from EP to the boost supply output capacitor ground and to the input supply ground return. Connect EP to a large copper ground plane for best thermal and electrical performance.

3.0 Absolute Maximum Ratings

Voltage (with respect to GND)

VIN, PVIN, EN, SDA, SCL, PWM, FLTB, SCTH, ILED, CS, COMP, FB, GATE .... -0.3V to +5.5V
STR0 to STR7 .... -0.3V to +40V
PVIN to VIN .... ±1V
PGND, CGND, EP .... -50mV to 50mV

Current (into pin)

VIN 50mA
GATE, PVIN .... ±1250mA
STR0 to STR7, CGND... 75mA
EP, PGND, GND ....-1000mA
All other pins ....-20mA to 20mA

Continuous Power Dissipation

24-Pin 4mm x 4mm VQFN (derate 25mW/°C above T_A = +70°C) 1850mW

Ambient Operating Temperature Range T_A = T_{MIN} to T_{MAX} .... -40°C to +85°C
Junction to Ambient Thermal Resistance (θ_{JA}), 4-Layer (Note 8) .... 29°C/W
Junction to Ambient Thermal Resistance (θ_{JA}), 2-Layer (Note 8) .... 38°C/W
Junction to Case Thermal Resistance (θ_{JC}) .... 8.6°C/W
Junction Temperature .... +125°C
Storage Temperature Range .... -65°C to +125°C
Lead Soldering Temperature, 10s .... +300°C

4.0 Electrical Characteristics

V_{VIN} = 5V, V_{EN} = 5V, Default Register Settings of Table 1, TA = -40°C to 85°C, unless otherwise noted. Typical values are at TA = +25°C

Parameter	Conditions and Notes		Min	Typ	Max	Unit
DC Electrical Characteristics						
VIN Operating Supply Voltage			4.5		5.5	V
VIN Operating Supply Current	All STRn outputs 100% duty				18	mA
VIN Shutdown Supply Current	EN = GND				1	µA
SDA, SCL, PWM, SYNC Input High Voltage			1.82			V
SDA, SCL, PWM, SYNC Input Low Voltage					0.72	V
Minimum PWM On-Time				400		ns
PWM, SYNC Input Frequency Range			20	200	50,000	Hz
SDA, FLTB Output Low Voltage	Sinking 6mA				0.4	V
EN Threshold	V_{EN} rising		1.5			V
ILED Regulation Voltage	Minimum R_{ILED} = 60kΩ			1.25		V
STR0 to STR7 LED Regulation Current	R_{ILED} = 100kΩ, TA= 25°C V_{STRn} = 1V		58.2	60.0	61.8	mA
STR0 to STR7 LED Current Load Regulation	R_{ILED} = 100kΩ V_{STRn} = 1V to 5V			0.15		%/V
STR0 to STR7 LED Current Matching	String to average of all strings		-3		3	%
STR0 to STR7 Minimum Headroom	V_{STRn} = 60mA			0.5		V
STR0 to STR7 Short Circuit Fault Threshold	R_{SCTH} = 1.0kΩ		3.98	4.96		V
FB Feedback Output Current	FBO DAC = 0xFF, V_{FB} = 0		224		350	µA
FB Feedback Output Current Step Size				1.1		µA
FBI Input Disable Threshold					50	mV
Thermal shutdown temperature	Temperature Rising, 10°C Hysteresis			135		°C
Boost Regulator Electrical Characteristics						
Switching Frequency			569	665	762	kHz
Gate Voltage Rise/Fall Time	C_{GATE} = 1nF			50		ns
CS Current Limit Threshold Voltage			75	111	147	mV
Maximum Duty Cycle	At factory set boost frequency			90.1		%
Minimum On Time	f_{BOOST} = 350kHz to 1MHz (contact factory for boost frequencies different from 625kHz)			241	300	ns
Boost Regulator Leading-Edge Blanking Period				130		ns
FB Regulation Voltage			2.4	2.5	2.6	V
I²C Switching Characteristics						
SCL Clock Frequency	1/t_{SCL}	Bus timeout disabled (Note 1)	0		1000	kHz
Bus Timeout Period	$t_{timeout}$	TA = 25°C (Note 7)	29	30		ms
STOP to START Condition Bus Free Time	t_{BUF}	(Note 7)	0.5			µs
Repeated START condition Hold Time	$t_{HD:STA}$	(Note 7)	0.26			µs
Repeated START condition Setup Time	$t_{SU:STA}$	(Note 7)	0.26			µs
STOP Condition Setup Time	$t_{SU:STOP}$	(Note 7)	0.26			µs
SDA Data Hold Time	$t_{HD:DAT}$	(Note 7)	0			ns
SDA Data Valid Acknowledge Time	$t_{VD:ACK}$	(Note 2) (Note 7)	0.05		0.55	µs
SDA Data Valid Time	$t_{VD:DAT}$	(Note 3) (Note 7)	0.05		0.55	µs
SDA Data Set-Up Time	$t_{SU:DAT}$	(Note 7)	100			ns
SCL Clock Low Period	t_{LOW}	(Note 7)	0.5			µs
SCL Clock High Period	t_{HIGH}	(Note 7)	0.26			µs
SDA, SCL Fall Time	t_f	(Note 4) (Note 5) (Note 7)			120	ns
SDA, SCL Rise Time	t_r	(Note 7)			120	ns
SDA, SCL Input Suppression Filter Period	t_{SP}	(Note 6) (Note 7)		50		ns

Note 1. Minimum SCL clock frequency is limited by the bus timeout feature, which resets the serial bus interface if either SDA or SCL is held low for timeout.
Note 2. tVD:ACK = SCL LOW to SDA (out) LOW acknowledge time.
Note 3. t$_{VD:DAT}$ = minimum SDA output data-valid time following SCL LOW transition.
Note 4. A master device must internally provide an SDA hold time of at least 300ns to ensure an SCL low state.
Note 5. The maximum SDA and SCL rise times is 300ns. The maximum SDA fall time is 250ns. This allows series protection resistors to be connected between SDA and SCL inputs and the SDA/SCL bus lines without exceeding the maximum allowable rise time.
Note 6. MSL3080 include input filters on SDA and SCL that suppress input noise less than 50ns
Note 7. Parameter is guaranteed by design and not production tested.
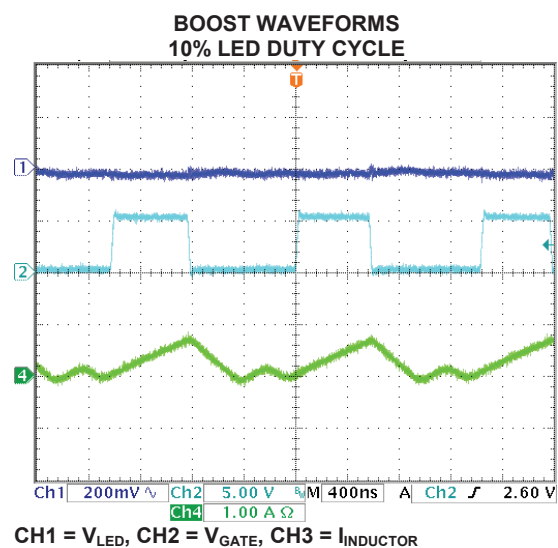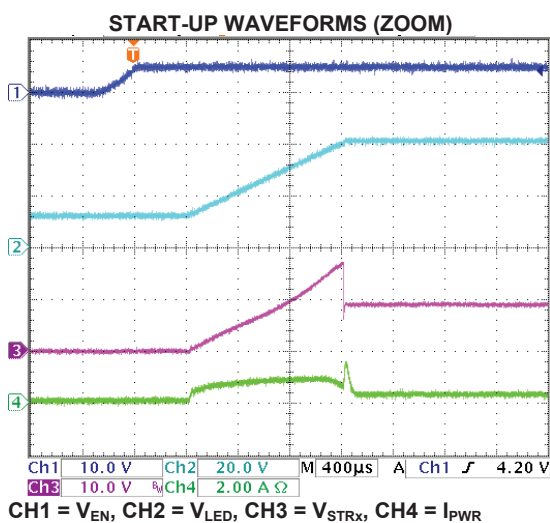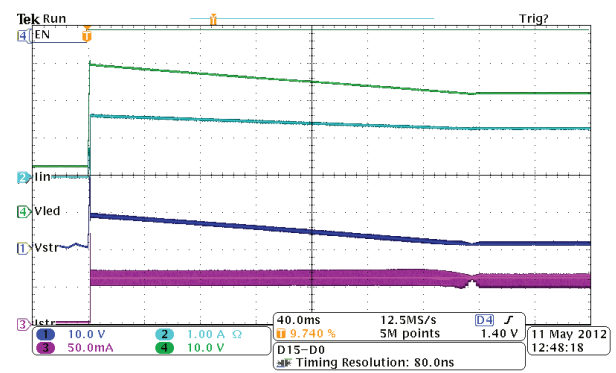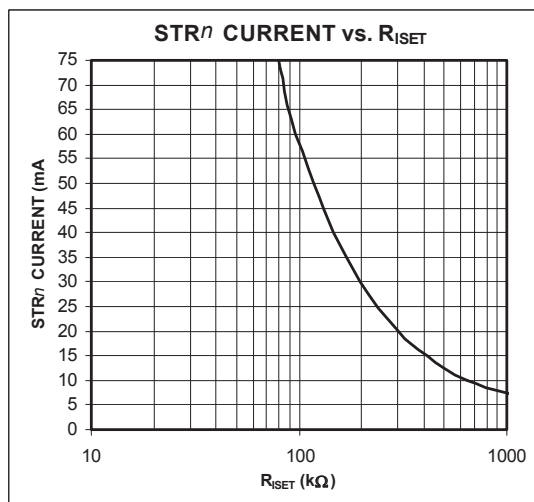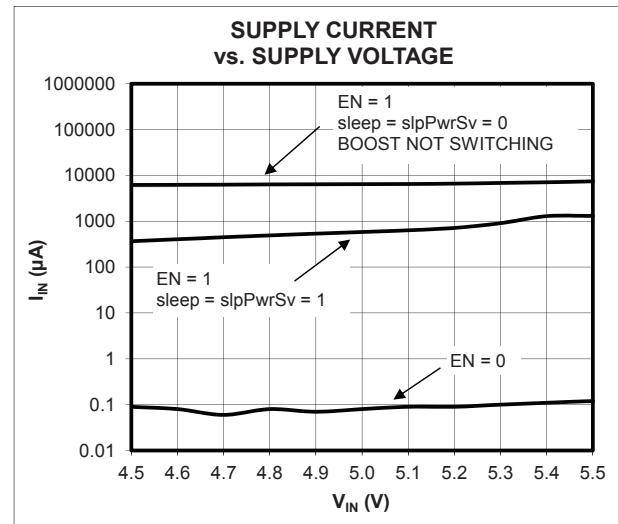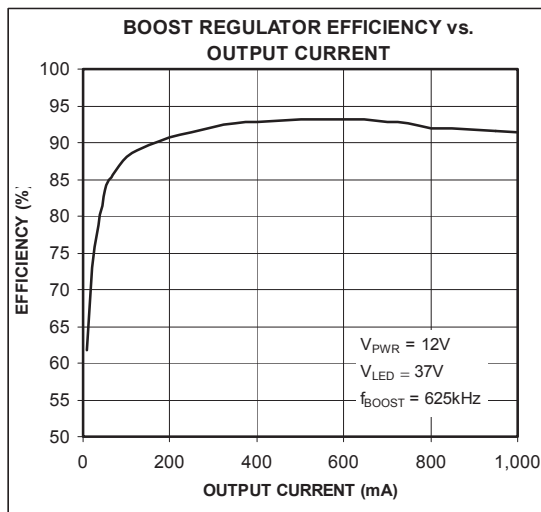Note 8. Per JEDEC specification JESD51-5 and JESD51-12.
Note 9. Tests performed at TA = 25°C, specifications over temperature guaranteed by design.

5.0 Typical Operating Characteristics

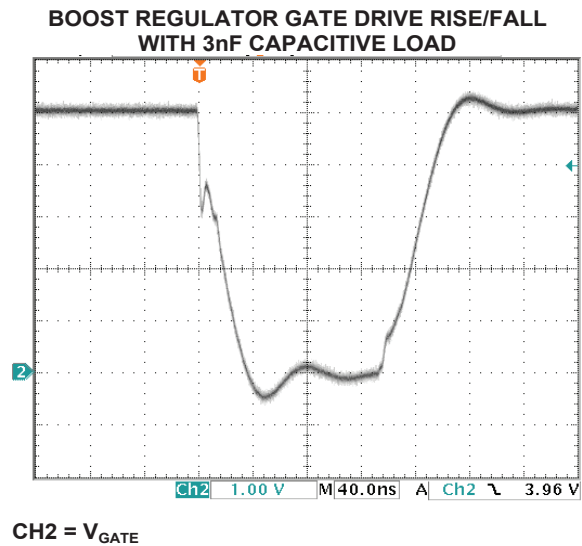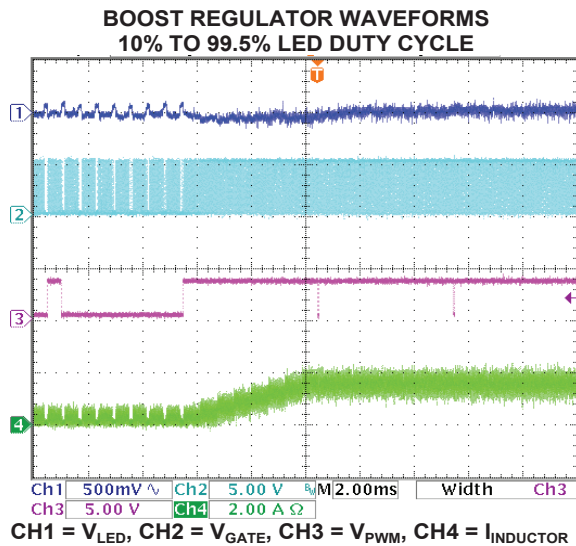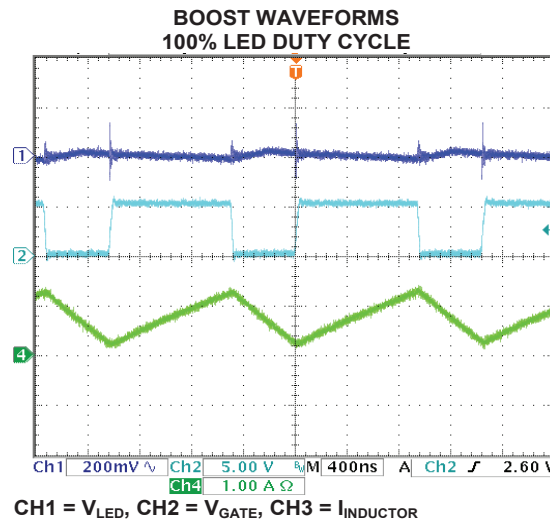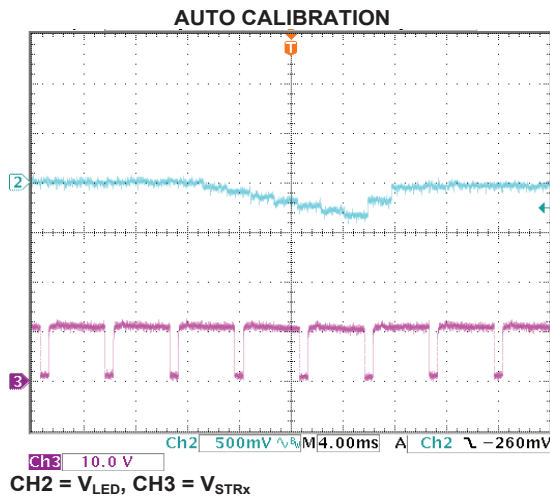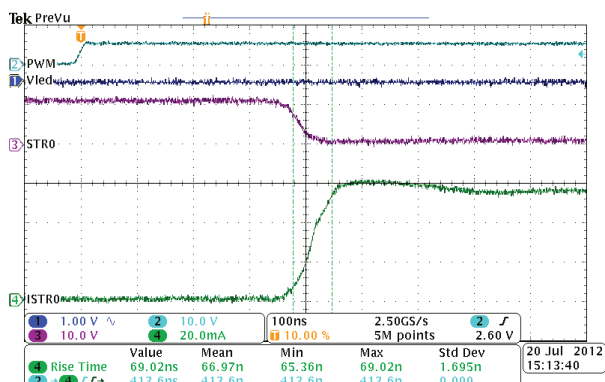(Typical Operating Circuit, unless otherwise stated, TA = +25°C, unless otherwise noted)

BOOST REGULATOR EFFICIENCY vs. OUTPUT CURRENT

$V_{PWR} = 12V$
$V_{LED} = 37V$
$f_{BOOST} = 625kHz$

SUPPLY CURRENT vs. SUPPLY VOLTAGE

EN = 1
sleep = slpPwrSv = 0
BOOST NOT SWITCHING

EN = 1
sleep = slpPwrSv = 1

EN = 0

STRn CURRENT vs. R$_{ISET}$

START-UP WAVEFORMS (ZOOM)

CH1 = V_{EN}, CH2 = V_{LED}, CH3 = V_{STRx}, CH4 = I_{PWR}

BOOST WAVEFORMS 10% LED DUTY CYCLE

CH1 = V_{LED}, CH2 = V_{GATE}, CH3 = $I_{INDUCTOR}$

5.0   Typical Operating Characteristics *(continued)*

(Typical Operating Circuit, unless otherwise stated, TA = +25°C, unless otherwise noted)

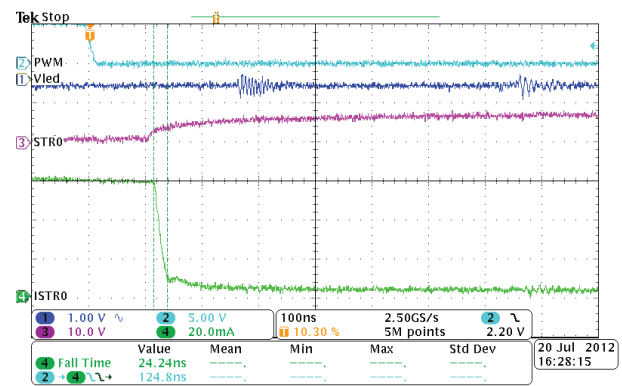### AUTO CALIBRATION

CH2 = V$_{LED}$, CH3 = V$_{STRx}$

BOOST WAVEFORMS
100% LED DUTY CYCLE

CH1 = V$_{LED}$, CH2 = V$_{GATE}$, CH3 = I$_{INDUCTOR}$

BOOST REGULATOR WAVEFORMS
10% TO 99.5% LED DUTY CYCLE

CH1 = V$_{LED}$, CH2 = V$_{GATE}$, CH3 = V$_{PWM}$, CH4 = I$_{INDUCTOR}$

BOOST REGULATOR GATE DRIVE RISE/FALL
WITH 3nF CAPACITIVE LOAD

CH2 = V$_{GATE}$

DRIVER RISE TIME

This scope image shows the voltage (VSTR0) and current (ISTR0) waveforms for string zero, and their turn-on rise times and delay from PWM rising. Also shown is the string power supply output (VLED), which shows little disturbance. For this photo string 0 is enabled with all other strings disabled.

DRIVER FALL TIME

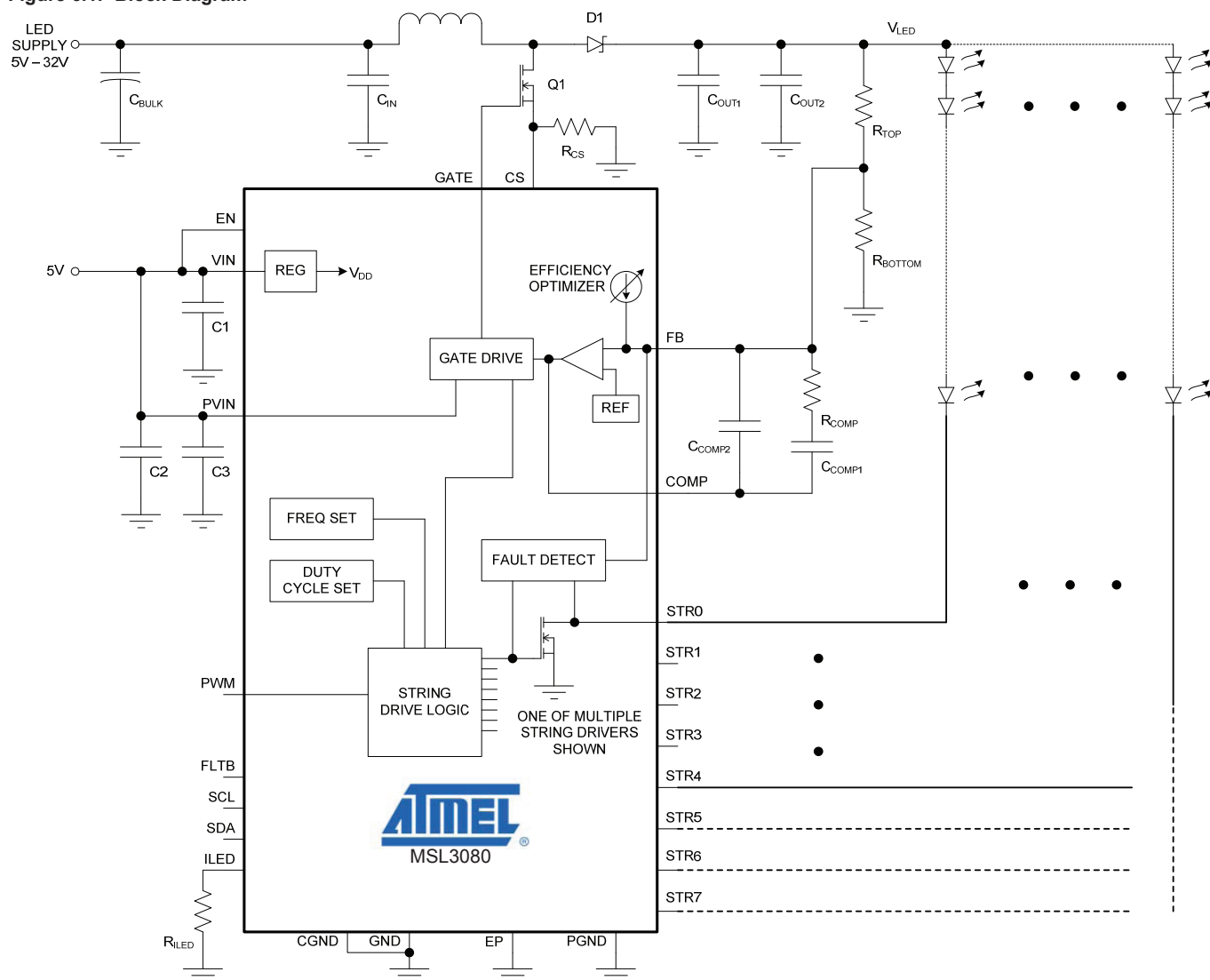This scope image shows the voltage (VSTR0) and current (ISTR0) waveforms for string zero, and their turn-off fall times. Also shown is the string power supply output (VLED), which shows very little disturbance. For this photo string 0 is enabled with all other strings disabled, and a 220pF capacitor in series with a 11Ω resistor in series is placed from STR0 to GND at the device.
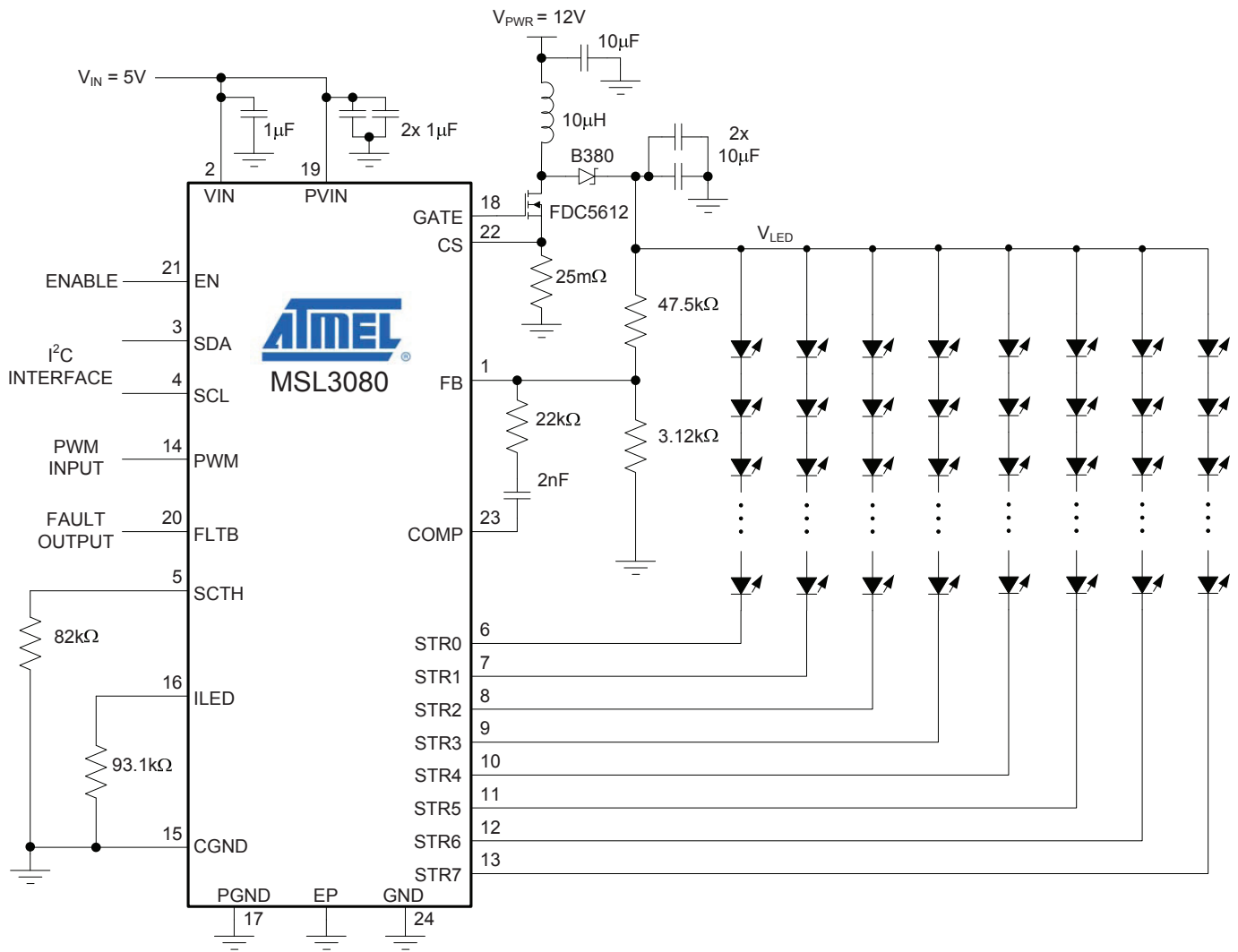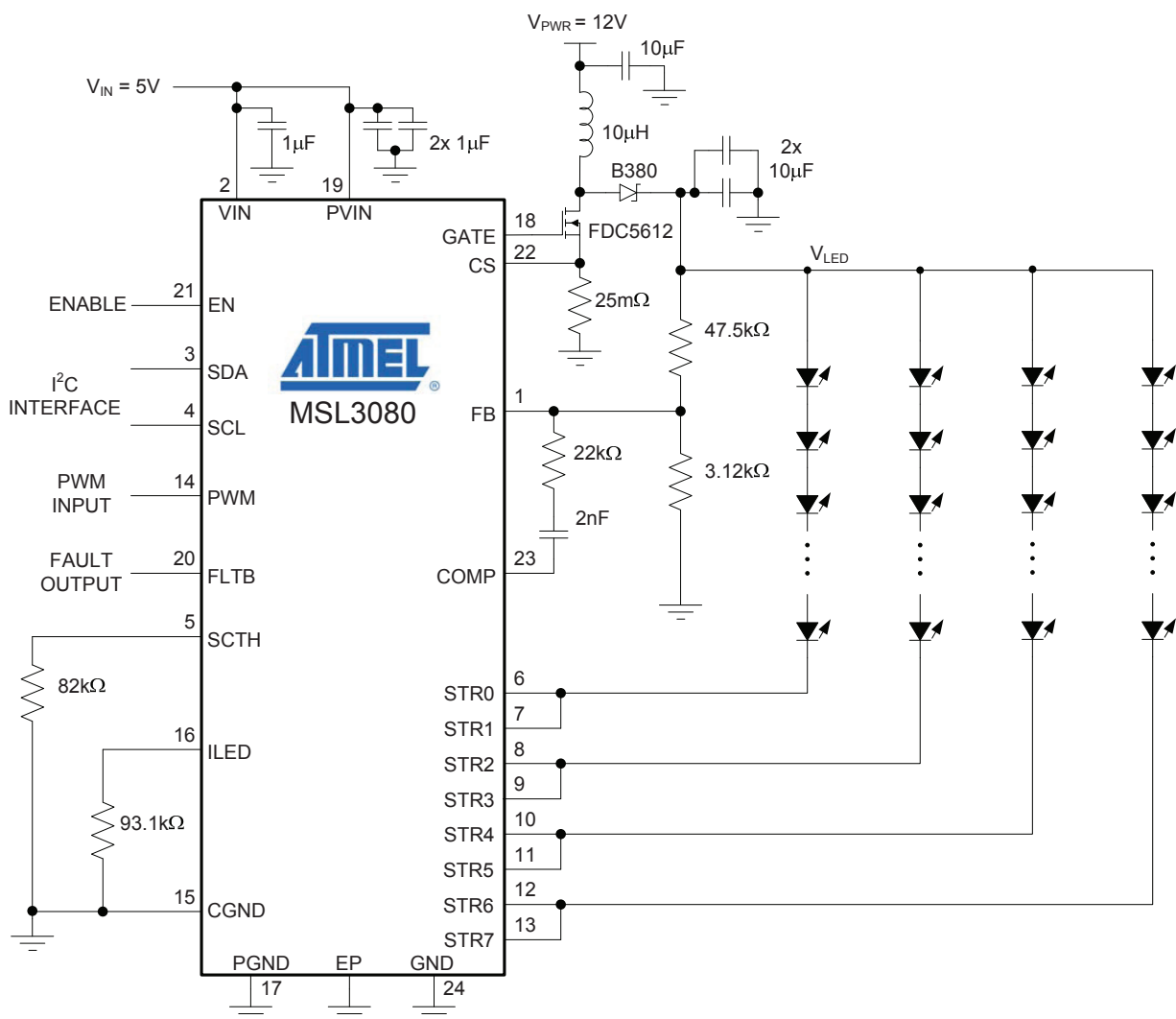
6.0 Block Diagram

Figure 6.1. Block Diagram

7.0   Typical Application Circuits

Figure 7.1.   Typical Operating Circuit for Eight 60mA Strings of 10 White LEDs each.

Figure 7.2. Typical Operating Circuit for Four 120mA Strings of 10 White LEDs each.

Figure 7.3. Typical Operating Circuit for One 480mA String of 10 White LEDs.

8.0 Detailed Description

The MSL3080 is an LED driver with eight internal current regulators, each capable of driving up to 60mA LED current. They feature an integrated boost regulator controller with a proprietary Efficiency Optimizer voltage control algorithm that lowers power use to the minimum required to assure LED current regulation. The driver outputs allow parallel connection to increase string current, at the expense of the number of strings, and a single resistor sets the current for all strings. The drivers support 12-bit PWM LED dimming ratios. The driver synchronizes LED dimming and controls duty cycle with a single external digital signal at the PWM input.

The MSL3080 includes comprehensive fault monitoring and automatic fault handling. Automatic fault handling allows the drivers to operate without any microcontroller or FPGA, while optional control via I²C allows customized fault handling and driver control for more complex applications. All drivers also feature optional register-set PWM dimming, fault management and other controls via the I²C serial interface; for interface information see the *"MSL3040/50/60/80/86/87/88 Programming Guide"*.

The small 4x4mm VQFN package allows a small overall LED driver solution, while maintaining high package power dissipation for high output power capability

8.1 LED Driver Comparison

Table 8.1. LED Driver Comparison with Similar Parts

PART	NUMBER OF LED STRINGS	MAX CURRENT PER STRING	PHASE SHIFTED STRING DRIVERS	INTERNAL BOOST CONTROLLER	RESISTOR SET LED SHORT CIRCUIT THRESHOLD	SEPARATE SYNC INPUT***	BEST FOR
MSL3086	8	60mA	YES	YES	YES	NO	MONITOR, INDUSTRIAL PANEL
MSL3087*	8	60mA	YES	NO	YES	NO	SMALL TV
MSL3088	8	60mA	YES	YES	NO	YES	SMALL TV
MSL3080	8	60mA	NO	YES	YES	NO	MONITOR, INDUSTRIAL PANEL
	4**	120mA	NO	YES	YES	NO	MONITOR, INDUSTRIAL PANEL
	2**	240mA	NO	YES	YES	NO	MONITOR, INDUSTRIAL PANEL
	1**	480mA	NO	YES	YES	NO	MONITOR, INDUSTRIAL PANEL
MSL3040*	4	120mA	YES	YES	YES	NO	MONITOR, AUTOMOTIVE
MSL3041*	4	120mA	YES	YES	YES	YES	MONITOR, AUTOMOTIVE
MSL3050*	5	60mA	NO	YES	YES	NO	INDUSTRIAL PANEL
	1**	300mA	NO	YES	YES	NO	INDUSTRIAL PANEL
MSL3060*	6	60mA	NO	YES	YES	NO	MONITOR, INDUSTRIAL PANEL
	3**	120mA	NO	YES	YES	NO	MONITOR, INDUSTRIAL PANEL
	2**	180mA	NO	YES	YES	NO	MONITOR, INDUSTRIAL PANEL
	1**	360mA	NO	YES	YES	NO	MONITOR, INDUSTRIAL PANEL

* Future product, contact factory for information.
** Drivers without phase shift allow parallel connection of string drive outputs for increased string current.
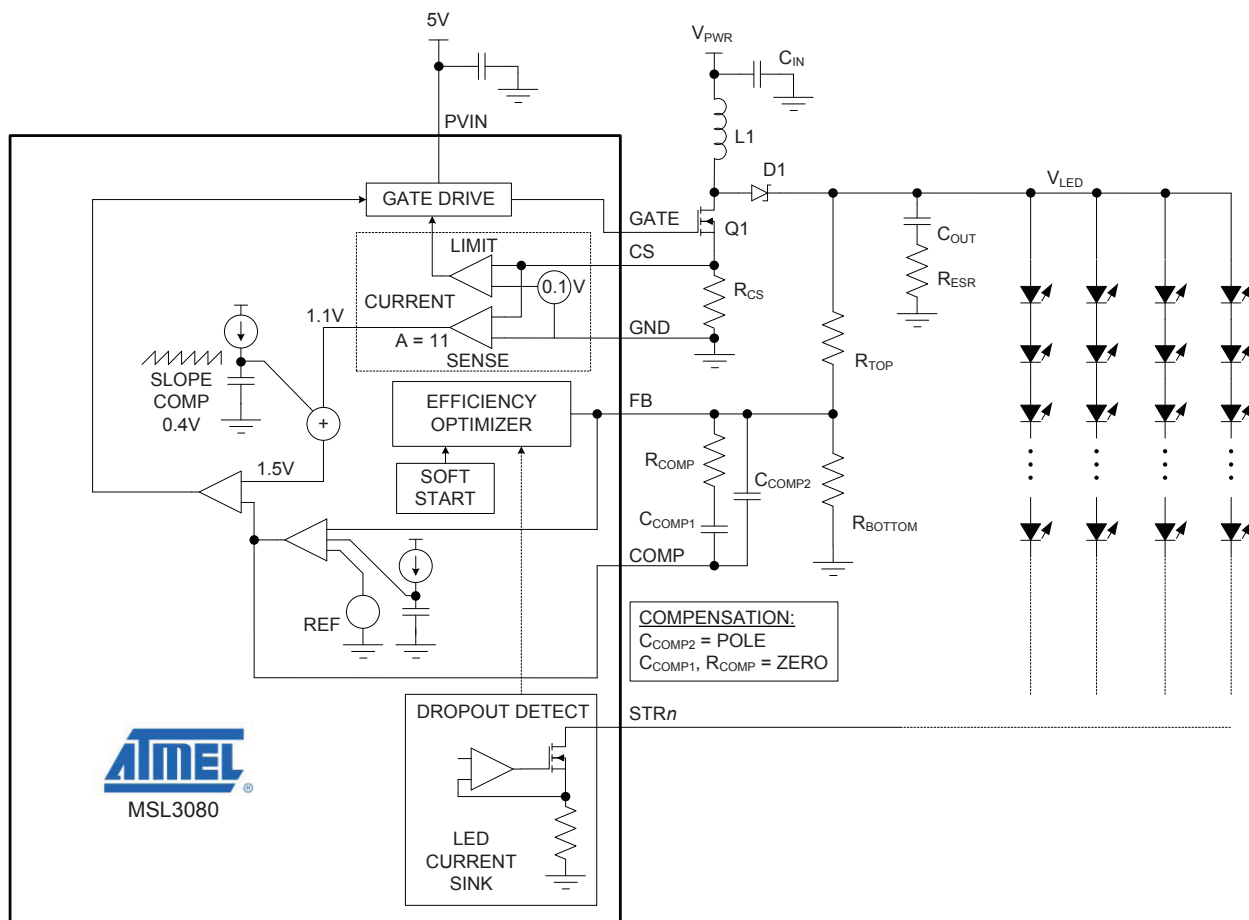*** Drivers with separate SYNC input expect two control signals, one for dimming duty cycle and one for dimming frequency.

8.2 Boost Regulator Overview

The MSL3080 boost regulator boosts the input voltage up to the regulated output voltage (for design details see the section *"Boost Regulator"* beginning on page 17, the following text presents an overview of the boost regulator controller). The boost regulator uses an external switching MOSFET, current sense resistor, inductor, rectifier, and input and output capacitors (Figure 8.1). External MOSFET and current sense resistor allow the boost regulator to operate over wide input and output voltage ranges, and LED currents. It includes a 2.5V reference voltage, fixed slope compensation and external voltage regulator compensation to optimize the control loop for each configuration. Because the boost regulator components are external it supports a number of converter topologies, such as SEPIC, flyback, and single-switch forward. The boost regulator includes soft-start, adjustable cycle-by-cycle current limiting, and output over-voltage fault detection.

Figure 8.1. Power Section of MSL3080

8.3 Error Amplifier

The internal error amplifier compares the external divided output voltage at FB to the internal 2.5V reference voltage to set the regulated output voltage, V_{LED}. The error amplifier output voltage at COMP is externally accessible; use it to compensate the voltage regulator. FB also drives the integrated boost over-voltage comparator that detects if the output voltage exceeds the regulation voltage, to generate a fault condition. The error amplifier internally controls the current mode PWM regulator.

8.4 Gate Driver

The gate driver drives the gate of the external boost regulator switching MOSFET. The drain of the switching MOSFET in turn drives the boost inductor and rectifier to boost the input voltage to the regulated output voltage. The gate driver sources and sinks up to 1A allowing fast switching speed and allows the use of MOSFETs with high gate capacitance. The gate driver power is separated from the internal circuitry power to reduce internal noise and to allow separate gate driver bypassing for optimal performance.

8.5 Soft-Start

The boost regulator includes a built in soft-start to prevent excessive input current overshoot at turn-on. The soft-start ramps the output regulation voltage from 0V at turn-on to the as-configured regulation output voltage over 1.6ms. Note that the boost regulator only controls output voltages greater than the input voltage; when the soft-start sets the regulation voltage below the input voltage, the actual output voltage remains at approximately the input voltage.

8.6 Boost Fault Monitoring and Protection

The boost regulator includes fault monitoring and protection circuits to indicate faults and prevent damage to the boost regulator or other circuitry. The boost regulator has cycle by cycle current limiting that prevents excessive current through the power MOSFET. The current limit is has a fixed threshold voltage across the current sense resistor, thus set the current limit by choosing the proper value current sense resistor.

The boost regulator includes an output over-voltage fault monitor that indicates a fault when the voltage at FB exceeds the 2.8V over-voltage protection (OVP) threshold. When an over-voltage fault occurs FLTB sinks current to GND to indicate that a fault has occurred. OVP fault is non-latching, the fault clears when the over-voltage condition disappears.

8.7 LED Current Regulators and PWM Dimming Modes

The MSL3080 includes eight open-drain LED current regulators that sink LED current up to 60mA per channel and sustain up to 40V, allowing them to drive up to 10 white LEDs each. The current regulators inform the Efficiency Optimizers, which in turn control the boost regulator output voltage to minimize LED voltage while maintaining sufficient headroom for the LED current regulators.

Set the LED regulation current using a single resistor from ILED to GND. LED dimming is by PWM, and is by default controlled through an external signal, or optionally by internal registers accessed through the I2C compatible serial interface (for interface information see the *"MSL3040/50/60/80/86/87/88 Programming Guide"*). The drivers feature synchronized dimming, where all PWM dimming outputs sink current in unison.

8.8 Efficiency Optimizer (EO)

The Efficiency Optimizer monitors the LED string drivers and controls the boost regulator output voltage to minimize LED current regulator overhead voltage while maintaining sufficient voltage for accurate current regulation. The Efficiency Optimizer injects a current into the boost regulator FB input node to reduce the boost regulator output voltage.

The Efficiency Optimizer has two modes of operation, initial calibration and auto calibration. Initial calibration happens at turn-on and optimizes boost regulator output voltage. Auto calibration happens once per second to re-optimize the boost output voltage in response to changing LED forward voltage due to aging or temperature effects.

8.9 Fault Monitoring and Auto-handling

The MSL3080 includes comprehensive fault monitoring and corrective action. The LED current regulators are monitored for LED string open circuit and LED short circuit faults. It also monitors the boost regulator for output over-voltage. Strings with LED Short Circuit or Open Circuit faults are turned off and ignored by the Efficiency Optimizer.

FLTB sinks current to GND when a fault is detected. The Boost Over-Voltage Fault does not latch, the fault goes away when the fault condition no longer exists and FLTB is released; all other faults latch. Clear faults by toggling EN low and then high, or by cycling input power off and on. Additionally, fault control is available through the I²C compatible serial interface; see the *"MSL3040/50/60/80/86/87/88 Programming Guide"* for information.

8.10 Internal Supervisory and LDO

The MSL3080 has a Power-On-Reset circuit that monitors VIN and allows operation when VIN exceeds 4.25V. The MSL3080 has built-in LDOs that generate 2.5V to power the logic and oscillator sections. An integrated supervisor ensures that the LDO and internal oscillator are stable before enabling the boost controller. The boost controller goes through a soft-start before the LED drivers are enabled.

8.11 Internal Oscillator

The MSL3080 includes a 20MHz internal oscillator that is divided down to drive the boost controller, and the LED PWM engine. The oscillator is factory trimmed. Contact the factory if required to change the 20MHz default oscillator frequency; available frequencies fall between 16MHz and 24MHz.

8.12 Over Temperature Shutdown

The MSL3080 includes automatic over-temperature shutdown. When the die temperature exceeds 135°C, the driver turns off, as if EN is pulled low, and is held off until the die temperature drops below 120°C, at which time it turns back on. While MSL3080 is in over-temperature shutdown the onboard regulators are off, register values reset to their power-on default values, and the serial interface is disabled.

8.13 Power Saving Modes

The MSL3080 has 3 primary power save modes available through the I^{2}C compatible serial interface. See the *"MSL3040/50/60/80/86/87/88 Programming Guide"* for information.

8.14 I^{2}C Serial Interface and Driver Control

The I^{2}C serial interface, whose use is optional, allows control of PWM dimming, fault monitoring, and various other control functions. For a detailed explanation of interface operation see the *"MSL3040/50/60/80/86/87/88 Programming Guide"*.

9.0 Application Information

9.1 Bypassing VIN and PVIN

Bypass VIN with a capacitor of at least 1µF. Bypass PVIN to PGND with at least 2µF. Place all bypass capacitors close to the MSL3080.

9.2 Setting the LED Current

Set the on-current for all LED strings with a resistor from ILED to GND. Choose the resistor using:

$$R_{ISET} = \frac{6050}{I_{LED}}\Omega,$$

where I_{LED} is the LED full-scale current in Amps.

The maximum LED current per-string is 60mA. Driving all eight strings with 60mA at high duty cycles and elevated ambient temperatures requires proper thermal management to avoid over-temperature shutdown. Connect the exposed pad (EP) to a large copper ground plane for best thermal and electrical performance.

9.3 Fault Monitoring and Automatic Fault Handling

The MSL3080 monitors the LED strings and boost regulator output voltage to detect LED short-circuit, LED string open-circuit and Boost Over-voltage faults. String faults latch the open drain fault output FLTB low. A boost over-voltage fault pulls FLTB low but does not latch.

When shorted LEDs are detected in a string, the driver disables and the Efficiency Optimizer stops monitoring it. The MSL3080 flags these strings as faults in registers 0x05 through 0x08, pulls FLTB low and recalibrates the LED power supply voltage. Set the short circuit voltage threshold with a resistor between SCTH and GND, as explained in the section "*Setting the LED Short-Circuit Threshold*" beginning on page 17. For information about the fault registers and the I²C compatible serial interface see the *"MSL3040/50/60/80/86/87/88 Programming Guide"*.

When an open circuit occurs, the Efficiency Optimizer detects a loss of current regulation which must persist for greater than 2 µs to be detected. The minimum on-time for the strings is 2 µs. In this case the Efficiency Optimizer increases the LED voltage (boost regulator output voltage), in an attempt to bring the LED current back in to regulation. This continues until the voltage is at the maximum level. The MSL3080 then determines that any LED strings that are not regulating current are open circuit. It disables those strings, flags them as faults in registers 0x05 through 0x08, pulls FLTB low and recalibrates the LED power supply voltage. When the boost regulator is at its maximum value fictitious LED short circuit faults can occur. Toggle EN low and then high to clear all faults and return the MSL3080 to controlling and monitoring all LED strings. Fault conditions that persist re-establish fault responses. For information about the fault registers and the I²C compatible serial interface see the *"MSL3040/50/60/80/86/87/88 Programming Guide"*.

9.4 Setting the LED Short-Circuit Threshold

When a given string, STRn, is sinking LED string current, the fault detection circuit monitors the STRn voltage. Typical optimized STRn on-voltage is 0.5V. When one or more LED's of a string are shorted, the STRn voltage increases above the nominal. When the voltage is above the Short-Circuit Threshold the fault circuit generates an LED short circuit fault. In most cases, two LEDs in a string must be shorted to cause a short circuit fault, but because LED V_F differs for different LEDs, the number of shorted LEDs required to generate a fault varies.Set the LED short-circuit threshold with a resistor from SCTH to GND using:
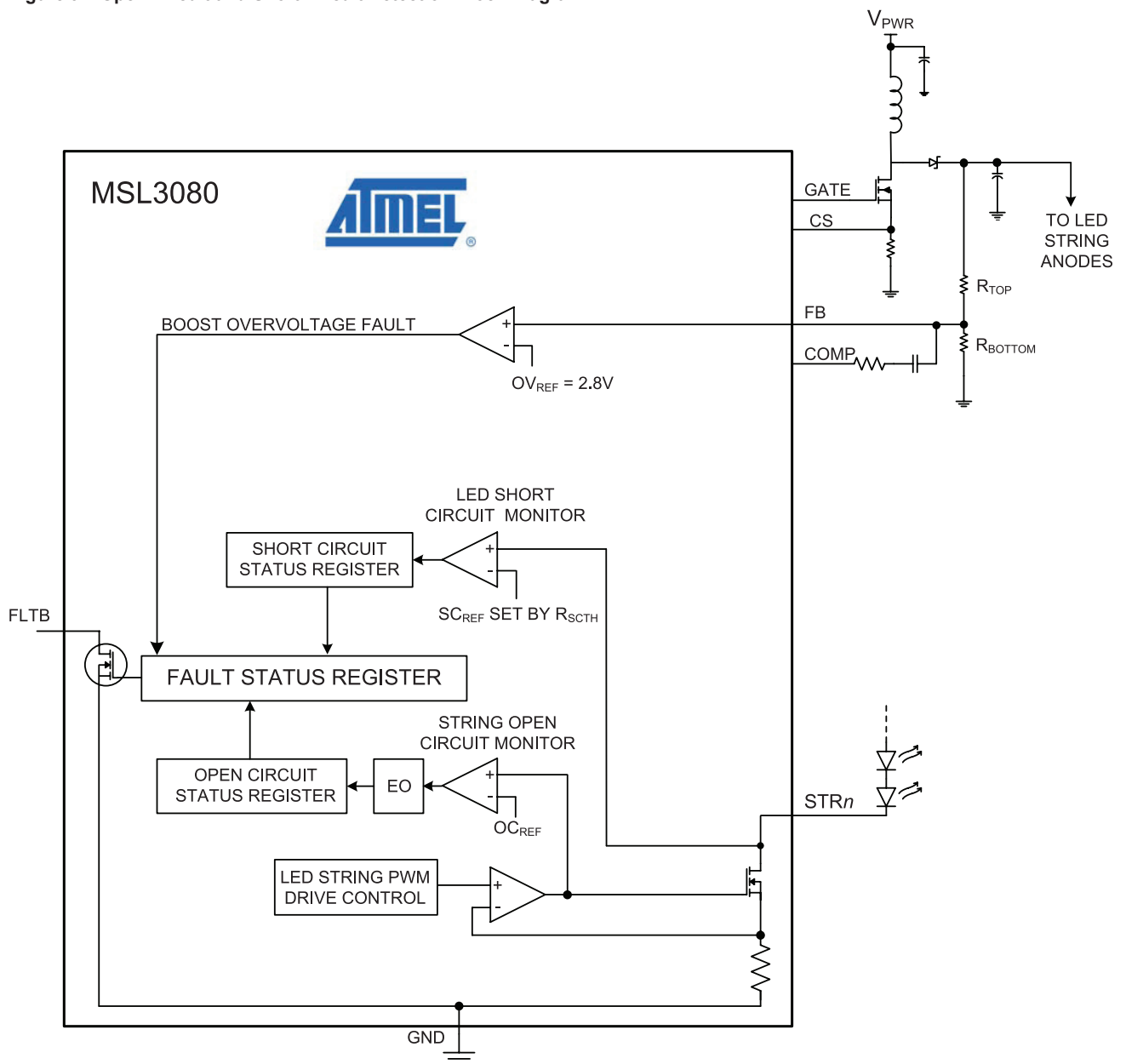
Table 9.1 Short Circuit Threshold Resistor

R$_{SCTH}$	Threshold Voltage
1.0kΩ (or GND)	4.9V
27kΩ	5.8V
68kΩ	6.8V
330kΩ (or open)	7.6V

R$_{SCTH}$ is measured only at power up, and when EN is taken high, to set the threshold level. Additionally, register 0x04 holds the Short Circuit Threshold level, changeable through the I²C compatible serial interface. For information about the Short Circuit Threshold register and the serial interface see the *"MSL3040/50/60/80/86/87/88 Programming Guide".*

Figure 9.1 Open-Circuit and Short-Circuit Detection Block Diagram

9.5 Boost Regulator

The boost regulator boosts the input voltage to the regulated output voltage that drives the LED anodes. The MSL3080 boost regulator uses an external MOSFET switch and current sense resistor, allowing a wide variety of input/output voltage combinations and load currents. The boost regulator switching frequency is 625kHz. Switching frequencies of 350kHz, 500kHz, 750kHz, 875kHz and 1Mhz are also available; contact the factory for information.

9.6 The Efficiency Optimizer (EO)

A voltage divider from the boost regulator output voltage to FB sets the regulation voltage (R_{TOP} and R_{BOTTOM} in Figure 8.1 on page 14). The EO improves power efficiency by dynamically adjusting the power supply output voltage to the minimum required to power the LEDs. This ensures that there is sufficient voltage available for LED current regulation, and good power supply noise rejection, while minimizing power dissipation. It does this by injecting a current into the FB input over 256 steps (8-bit resolution).

When turned on, either by applying input voltage to VIN while EN is high, or by driving EN high with voltage applied to VIN, the EO begins an initial calibration cycle by monitoring the LED current regulators. If all the current regulators maintain LED current regulation the EO output current is increased to reduce the boost output voltage. After the 4ms power supply settling time, it rechecks the regulators, and if they continue to maintain regulation the process repeats until one or more current regulator loses regulation. This step requires that the strings are turned on for a minimum of 2 μs to detect current regulation. The EO then decreases the output current to increase boost output voltage, giving the regulator enough headroom to maintain regulation with minimal power dissipation. The oscilloscope picture Figure 9.2 shows this procedure. The EO automatically re-calibrates V_{OUT} every 1 second, and at any time increases the boost voltage when detects an LED string with insufficient current.

Figure 9.2 Efficiency Optimizer (EO)

9.7 Setting the Boost Regulator Output Voltage

Select the voltage divider resistors (R_{TOP} and R_{BOTTOM} in Figure 8.1 on page 14) to set the boost regulator output voltage by first determining $V_{OUT(MIN)}$ and $V_{OUT(MAX)}$, the required minimum and maximum LED string anode power supply (boost regulator) voltage, using:

$$V_{OUT(MIN)} = \left(V_{f(MIN)} \times [\# ofLEDs]\right) + 0.5 \qquad \text{and} \qquad V_{OUT(MAX)} = \left(V_{f(MAX)} \times [\# ofLEDs]\right) + 0.5$$

where $V_{f(MIN)}$ and $V_{f(MAX)}$ are the LED's minimum and maximum forward voltage drops at the full-scale current set by R_{ILED} (page 17). For example, if the LED minimum forward voltage is $V_{f(MIN)}$ = 3.5V and maximum is $V_{f(MAX)}$ = 3.8V, using 10 LEDs in a string, the total minimum and maximum voltage drop across a string is 35V and 38V. Adding allowance of 0.5V for the current regulator headroom brings $V_{OUT(MIN)}$ to 35.5V and $V_{OUT(MAX)}$ to 38.5. Next determine R_{TOP} using:

$$R_{TOP} = \frac{V_{OUT(MAX)} - V_{OUT(MIN)}}{350 \times 10^{-6}} \, \Omega$$

Where 350 x 10^{-6} is the maximum EO output current.

Then determine R_{BOTTOM} using:

$$R_{BOTTOM} = R_{TOP} \times \frac{2.5}{V_{OUT(MAX)} - 2.5} \, \Omega$$

where 2.5V is the internal reference voltage.

9.8 Choosing the Input and output Capacitors

The input and output capacitors carry the high frequency current due to the boost regulator switching. The input capacitor prevents this high frequency current from travelling back to the input voltage source, reducing conducted and radiated noise. The output capacitor prevents high frequency current to the load, in this case the LEDs, and also prevents conducted and radiated noise. The output capacitors also have a large effect on the boost regulator loop stability and transient response, and so are critical to optimal boost regulator operation.

Use ceramic input and output capacitors that keep their rated capacitance values at the expected operating voltages. The **Typical Application Circuit** on page 10 shows recommended values for and 10 LEDs and 60mA per string. Use a bulk electrolytic capacitor where power enters the circuit board.

9.9 Choosing the Inductor

The boost regulator inductor takes the current from the input source and directs that current to the load. Using the proper inductor is critical to proper boost regulator operation. Choose an inductor with sufficient inductance to keep the inductor ripple current within limits, and with sufficient current handling capability for steady-state and transient conditions.

The boost regulator switching causes ripple current through the inductor. The current rises during the on-time and falls during the off time. The slope of the inductor current is a function of the voltage across the inductor, and so the total change in current, ΔI_L, is the current slope multiplied by the time in that phase (on time, t_{ON}, or off time, t_{OFF}). In steady-state, where the load current, input voltage, and output voltage are all constant, the inductor current does not change over one cycle, and so the amount the current rises during the on time is the same as the amount the current drops during the off time. Calculate the duty cycle (equal to the on-time divided by the switching period) using:

$$D \approx \frac{V_{OUT} - V_{IN}}{V_{IN}}$$

where V_{OUT} is the output voltage and V_{IN} is the input voltage. Calculate the on-time in seconds using:

$$t_{ON} = \frac{D}{f_{SW}} = \frac{V_{OUT} - V_{IN}}{V_{IN} \times f_{SW}}$$

where f_{SW} is the boost regulator switching frequency. Calculate the inductor ripple current using:

$$\Delta I_L = \frac{V_{IN} \times t_{ON}}{L} = \frac{V_{IN}[V_{OUT} - V_{IN}]}{V_{IN} \times f_{SW} \times L}$$

where L is the inductance value in Henrys. Choose a value for L that produces a ripple current in the range of 25% to 50% of the steady state DC inductor current. The steady state DC inductor current is equal to the input current. Estimate the steady-state DC input current using:

$$I_{IN} \approx I_{LOAD} \times \left[\frac{V_{OUT}}{V_{IN}}\right]$$

where I_{LOAD} is the sum of all strings steady-state LED currents with all LEDs on simultaneously, V_{OUT} is the maximum (un-optimized) boost regulator output voltage, and V_{IN} is the minimum boost regulator input voltage.

Inductors have two types of maximum current ratings, RMS current and saturation current. Make sure that the peak inductor current is less than the saturation current rating. Note that during load current transients, which occur whenever the LEDs are turned on or off (due to PWM dimming), the inductor current may overshoot its steady state value. How much it overshoots depends on the boost regulator loop dynamics. If unsure of the loop dynamics, a typical value to use for the overshoot is 50% of the steady-state current. Add half of the inductor ripple current to this value to determine the peak inductor current. With inductor ripple current in the 25% to 50% range, estimate the inductor RMS current as 115% of the DC steady state inductor current.

9.10 Setting the External MOSFET Current Limit

The current sense resistor, connected from the switching MOSFET source to GND, sets the boost regulator current limit. The cycle-by-cycle current limit turns-off the boost regulator switching MOSFET when the current sense input detects instantaneous current above the current limit threshold. This causes the current to drop until the end of the switching cycle. The current limit threshold is 100mV typical, and 75mV minimum. Choose the current sense resistor value to set the current limit using:

$$R_{CS} = \frac{0.111}{I_{L(MAX)}} \Omega$$

where $I_{L(MAX)}$ is the maximum inductor current. When R_{CS} is not equal to a standard 1% resistor value use the next lower value.

9.11 Choosing the Switching MOSFET

The MSL3080 uses an external logic level MOSFET to drive the boost converter. Choose a MOSFET that can pass at least twice the peak inductor current, and that minimizes simultaneously both the MOSFET on-resistance, R_{DSon}, and gate charge for fast switching speed. Make sure that the MOSFET drain-source voltage rating is above the maximum un-optimized boost output voltage, with some extra margin for voltage overshoot due to excess circuit board stray inductance and output rectifier recovery artefacts. Assure that the MOSFET is heat sunk to withstand the worst-case power dissipation while maintaining die temperature within the MOSFET ratings.

9.12 Choosing the Output Rectifier

The output rectifier passes the inductor current to the output capacitor and load during the switching off-time. Due to the high boost regulator switching frequency use a Schottky rectifier. Use a Schottky diode that has a current rating sufficient to supply the load current, and a voltage rating higher than the maximum boost regulator output voltage. Schottky rectifiers have very low on voltage and fast switching speed, however at high voltage and temperatures Schottky leakage current can be significant. Make sure that the rectifier power dissipation is within the rectifier specifications. Place the MOSFET and rectifier close together and as close to the output capacitor(s) as possible to reduce circuit board radiated emissions.

9.13 Loop Compensation

Use a series RC network from COMP to FB to compensate the MSL3080 regulation loop (Figure 8.1 on page 14). The regulation loop dynamics are sensitive to output capacitor and inductor values. To begin, determine the right-half-plane zero frequency:

$$f_{RHPZ} = \left[\frac{V_{IN}}{V_{OUT}}\right]^2 \text{ x } \left[\frac{R_{LOAD}}{2\pi L}\right]$$

where R_{LOAD} is the minimum equivalent load resistor, or

$$R_{LOAD} = \frac{V_{OUT}}{I_{OUT(MAX)}}$$

The output capacitance and type of capacitor affect the regulation loop and method of compensation. In the case of ceramic capacitors the zero caused by the equivalent series resistance (ESR) is at such a high frequency that it is not of consequence. In the case of electrolytic or tantalum capacitors the ESR is significant, so must be considered when compensating the regulation loop. Determine the ESR zero frequency by the equation:

$$f_{ESRZ} = \frac{1}{2\pi \times ESR \times C_{OUT}}$$

where C_{OUT} is the value of the output capacitor, and ESR is the Equivalent Series Resistance of the output capacitor. Assure that the loop crossover frequency is at least 1/5th of the ESR zero frequency.

Next determine the desired crossover frequency as 1/5th of the lower of the ESR zero f_{ESRZ}, the right-half-plane zero f_{RHPZ} or the switching frequency f_{SW}. The crossover frequency equation is:

$$f_C = \left[\frac{R_{COMP}}{R_{TOP}}\right] \times \left[\frac{R_{LOAD}}{11 \times R_{CS}}\right] \times \left[\frac{1}{2\pi \times R_{LOAD} \times C_{OUT}}\right]$$

where f_C is the crossover frequency, R_{TOP} is the top side voltage divider resistor (from the output voltage to FB), R_{COMP} is the resistor of the series RC compensation network. Rearranging the factors of this equation yields the solution for R_{COMP} as:

$$R_{COMP} = R_{TOP} \times 11 \times R_{CS} \times 2\pi \times f_C \times C_{OUT} .$$

These equations are accurate if the compensation zero (formed by the compensation resistor R_{COMP} and the compensation capacitor C_{COMP}) happens at a lower frequency than crossover. Therefore the next step is to choose the compensation capacitor such that the compensation zero is 1/5th of the crossover frequency, or:

$$f_{COMPZ} = \frac{f_C}{5} = \frac{1}{2\pi \times R_{COMP} \times C_{COMP}} .$$

Solving for C_{COMP}:

$$C_{COMP} = \frac{5}{2\pi \times R_{COMP} \times f_C} .$$

Example:

As an example, set the maximum (un-optimized) output voltage to 39V, using voltage divider as follows:

R_{TOP} = 49.9k
R_{BOTTOM} = 3.40k

Let the load current be 800mA maximum, use 10uH inductor, a 20μF output capacitor, a 12V input voltage, a 12mΩ R_{CS}, and the switching frequency is 625kHz.

$$R_{LOAD} = \frac{V_{OUT}}{I_{LOAD}} = \frac{39V}{0.8A} = 48.75\Omega$$

$$f_{RHPZ} = \left[\frac{V_{IN}}{V_{OUT}}\right]^2 \times \left[\frac{R_{LOAD}}{2\pi L}\right] = \left[\frac{12}{39}\right]^2 \times \left[\frac{48.75}{2\pi \times (10 \times 10^{-6})}\right] \approx 73kHz$$

Set the crossover frequency to 1/5th f_{RHPZ}:

$$f_C = \frac{f_{RHPZ}}{5} \approx 14.6kHz .$$

Next calculate the compensation resistor value to achieve the 15kHz crossover frequency, or

$$R_{COMP} = R_{TOP} \times 11 \times R_{CS} \times 2\pi \times f_C \times C_{OUT} = 49.9k \times 11 \times .025 \times 2\pi \times 15k \times 20\mu F \approx 25.9k\Omega$$

Then calculate the compensation capacitor, C_{COMP}, to set the compensation zero to 1/5th of the crossover frequency, or 3kHz

$$C_{COMP} = \frac{1}{2\pi \times R_{COMP} \times f_{COMPZ}} = \frac{1}{2\pi \times 25k \times 3k} \approx 2.1nF .$$

When laying out the circuit board, place the voltage divider resistors and compensation resistor/capacitors as close to the MSL3040/41 as possible and minimize trace lengths connected to COMP and FB.

10.0 LED Dimming Control

10.1 External and I²C Control of LED Brightness

Control LED brightness using Pulse Width Modulation (PWM) with a PWM signal applied to the external PWM input. The LED PWM dimming occurs at the same frequency and duty cycle as the input signal. For all drivers, use PWM input frequency between 20Hz and 50kHz and duty cycle between 0% and 100%. Additionally, internal registers, accessed using the I2C compatible serial interface, allow control of the PWM dimming frequency and duty cycle. For programming details see the **"MSL3040/50/60/80/86/87/88 Programming Guide"**.

11.0 Ordering Information

Table 11.1 Ordering Information

PART	DESCRIPTION	PKG
MSL3080-IU	8-CH LED driver with integrated boost controller and resistor based LED Short Circuit threshold setting, with single PWM input.	24 pin 4 x 4 x 0.75mm VQFN