Atmel LED Drivers

MSL2010

Single String Linear constant current LED Controller with Integrated DC/DC Boost Controller

Features

- Integrated Boost Controller
- Drives external N-Ch MOSFETS
- Over-Temperature Fault Detection
- 8-bit DAC for peak current control
- PWM Input for Dimming Duty Cycle
- Linear current control for ripple-free LED current regulation
- 8-bit Efficiency Optimizer Minimizes Power Use
- ± 3% Current Accuracy
- I^2C Serial Interface (use Optional)
- 32 Bytes Free RAM, 32 Bytes Free EEPROM
- 24-Pin QFN Package
- -40°C To +105°C Operating Temperature Range

Typical Applications

- General and Architectural Lamps
- Down Lights and Recessed Lights
- PAR Lamps
- DC Input LED lamps

1. Introduction

The MSL2010 LED string driver features a constant off-time Boost Controller and provides very accurate, no ripple, linear controlled string current. The Atmel patent-pending Efficiency Optimizer (EO) controls the switch-mode converter output, optimizing the output voltage to achieve maximum power efficiency. Both the switching and linear controllers drive external MOSFETs to provide flexibility over a wide range of power levels (LED currents and voltages) and extremely low LED ripple current.

The MSL2010 operates from a 9.5V to 15V power supply. The Boost controller voltage regulation loop uses a constant off-time control algorithm to achieve stable control with good transient behavior. For flexibility of design, off-time is set with an external resistor. External loop compensation offers additional flexibility for the Boost Controller.

An I^2C interface provides access to the control registers, and to 32 bytes of RAM. Integrated non-volatile EEPROM memory, also accessed through the I^2C serial interface, allows configuration at final test in the case that the factory default settings must be modified.

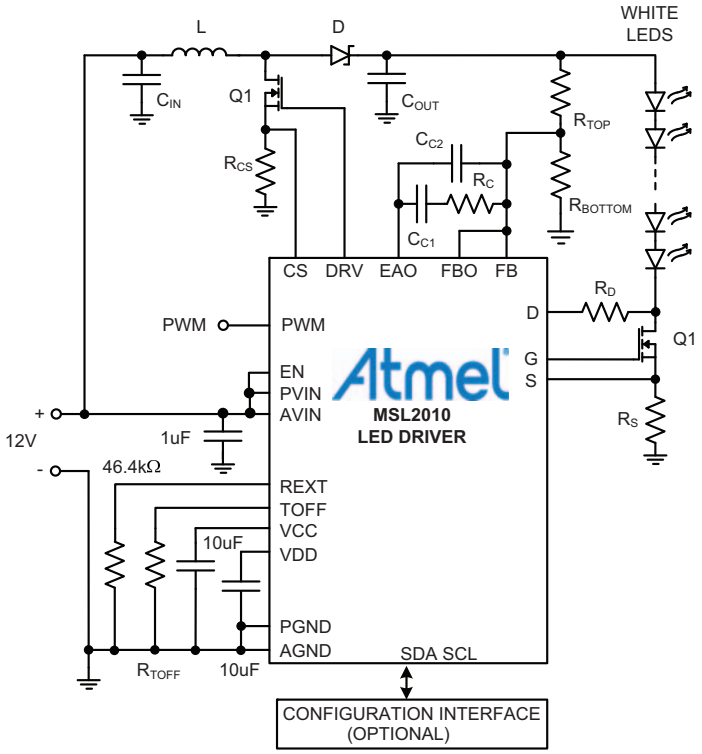
The MSL2010 is available in the space-saving 24-pin 4x4mm QFN package and operates over the extended -40°C to 105°C operating range.

2. Ordering Information

Ordering code	Description	Package[1]
MSL2010	One String LED Driver with DC-DC Controller	4 x 4mm 24-pin QFN

Note: 1. Lead-Free, Halogen-Free, RoHS Compliant Package

3. Application Circuit



4. Absolute Maximum Ratings

Voltage with respect to AGND		
	AVIN, PVIN, EN	-0.3V to +16.5V
	VCC, PWM, FLTB, SDA, SCL, TOFF, REXT, FBO	-0.3V to +5.5V
	VDD	-0.3V to +2.75V
	CS, S	-0.3V to VDD+0.3V
	D	-0.3V to +22V
	G, DRV	-0.3V to VIN+0.3V
	PGND, AGND	-0.3V to +0.3V

Current (into pin)		
	AVIN, PVIN, DRV, G (average)	100mA
	PVIN (peak, ≤1% duty)	1A
	DRV, G (peak, ≤1% duty)	±1A
	PGND (peak, ≤1% duty)	-1A
	AGND, PGND (average)	-100mA
	All other pins	±10mA

Continuous Power Dissipation at 70°C		
	24-Pin 4mm x 4mm VQFN (derate 21.8mW/°C above TA = +70°C)	1200mW

Ambient Operating Temperature Range	-40°C to +105°C
Junction Temperature	+125°C
Storage Temperature Range	-65°C to +125°C
Lead Soldering Temperature, 10s	+300°C

5. Electrical Characteristics

AVIN = PVIN = 12V, -40°C ≤T_A ≤ 105°C, Typical Operating Circuit, unless otherwise noted.
Typical values at T_A = +25°C.

Table 5-1. DC electrical characteristics

Parameter	Conditions	Min.	Typ.	Max.	Unit
AVIN, PVIN Operating Supply Voltage		9.5	12	15	V
AVIN Operating Supply Current	LEDs on at PWM = 100%, serial interface idle		10		mA
AVIN Disable Supply Current	V_{EN} = 0, all digital inputs = 0			5	µA
VCC Regulation Voltage	I_{VCC} = 10mApeak(1)	4.5	5	5.5	V
VDD Regulation Voltage	I_{VDD} = 10mApeak(1)	2.25	2.5	2.75	V
PWM, SCL, SDA Input High Voltage		0.7∗V_{VDD}			V
PWM, SCL, SDA Input Low Voltage				0.3∗V_{VDD}	V
EN Input High Voltage		2			V
EN Input Low Voltage				0.5	V
EN Input Hysteresis			100		mV
SDA, FLTB Output Low Voltage	Sinking 6mA			0.3	V
SCL, SDA, PWM, FLTB leakage current		-5		5	µA
S Current Sense Regulation Voltage	MREF = 0x64	194	200	206	mV
S Current Sense Regulation Voltage Accuracy	Main string at 100% duty cycle, T_A = 25°C, MREF = 0x64	-3		+3	%
S Current Sense Regulation Voltage Temperature Coefficient			-220		ppm/ºC
G Maximum Output Voltage		AVIN – 3.5		AVIN – 2.0	V
D Regulation Threshold	EOCTRL = 0xE5	0.9	1	1.1	V
CS Current Sense Regulation Voltage	CAREF = 0x64		200		mV
EA Unity Gain Bandwidth			7		MHz
EA Open Loop Gain			100		dB
DRV Impedance	V_{DRV} = 12V, I_{DRV} = 20mA		5.6	9	Ω
	V_{DRV} = 0V, I_{DRV} = -20mA		5.6	9	Ω
FBO Full Scale Current		170	255	340	µA
FBO LSB Current			1.0		µA
Thermal Shutdown Temperature	Temperature rising		133		°C
Thermal Shutdown Hysteresis			15		°C

Note: 1. Additional decoupling may be required when pulling current from VCC and/or VDD in noisy environments

Table 5-2. AC electrical characteristics

Parameter	Conditions	Min.	Typ.	Max.	Unit
DRV t_{OFF} timing	R_{TOFF} = 46.5kΩ		0.5		µs
PWM Input Frequency	(1)	60		10,000	Hz
PWM Duty Cycle		1		100	%
PWM Duty Cycle Resolution			0.4		%

Note: 1. 2µs minimum on time, 0% duty cycle is supported. PWM between 0% and 1% not guaranteed

Table 5-3. I^2C switching characteristics

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
SCL Clock Frequency		(1)	0.05		1,000	kHz
STOP to START Condition Bus Free Time	t_{BUF}		0.5			µs
Repeated START condition Hold Time	$t_{HD:STA}$		0.26			µs
Repeated START condition Setup Time	$t_{SU:STA}$		0.26			µs
STOP Condition Setup Time	$t_{SU:STOP}$		0.26			µs
SDA Data Hold Time	$t_{HD:DAT}$		5			ns
SDA Data Valid Acknowledge Time		(2)	0.05		0.55	µs
SDA Data Valid Time		(3)	0.05		0.55	µs
SDA Data Set-Up Time	$t_{SU:DAT}$		100			ns
SCL Clock Low Period	t_{LOW}		0.5			µs
SCL Clock High Period	t_{HIGH}		0.26			µs
SDA, SCL Fall Time	t_F	(4), (5)			120	ns
SDA, SCL Rise Time	t_R				120	ns
SDA, SCL Input Suppression Filter Period		(6)		50		ns
Bus Timeout	$t_{TIMEOUT}$	(1)		25		ms

Notes:
1. Minimum SCL clock frequency is limited by the bus timeout feature, which resets the serial bus interface when either SDA or SCL is held low for $t_{TIMEOUT}$.
2. SDA Data Valid Acknowledge Time is SCL LOW to SDA (out) LOW acknowledge time.
3. SDA Data Valid Time is minimum SDA output data-valid time following SCL LOW transition.
4. A master device must internally provide an SDA hold time of at least 300ns to ensure an SCL low state.
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.
6. Includes input filters on SDA and SCL that suppress noise less than 50ns.

6. Typical Operating Characteristics

Figure 6-1. Istr (String Current) rising.

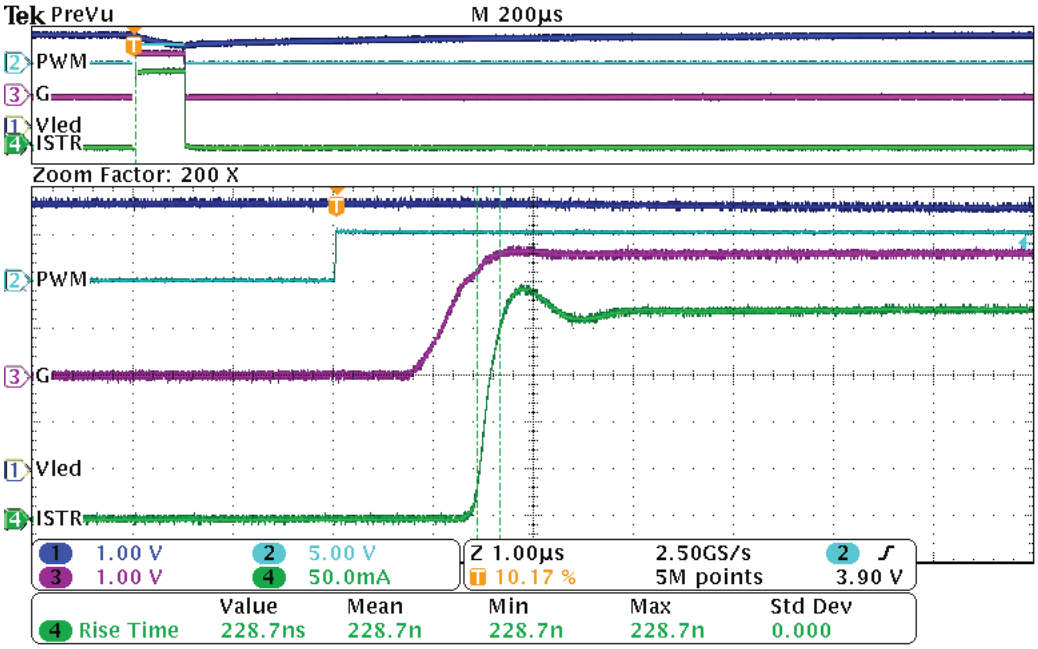


Figure 6-2. Istr (String Current) falling.

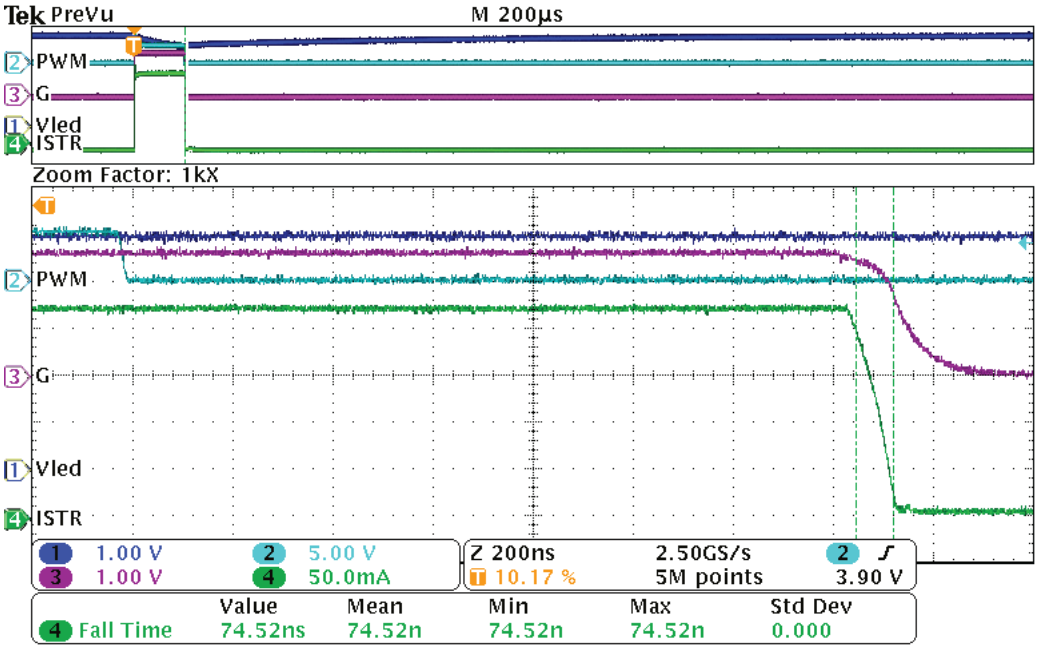


Figure 6-3. Start-up behavior, PWM = 10% duty cycle (Test conditions).

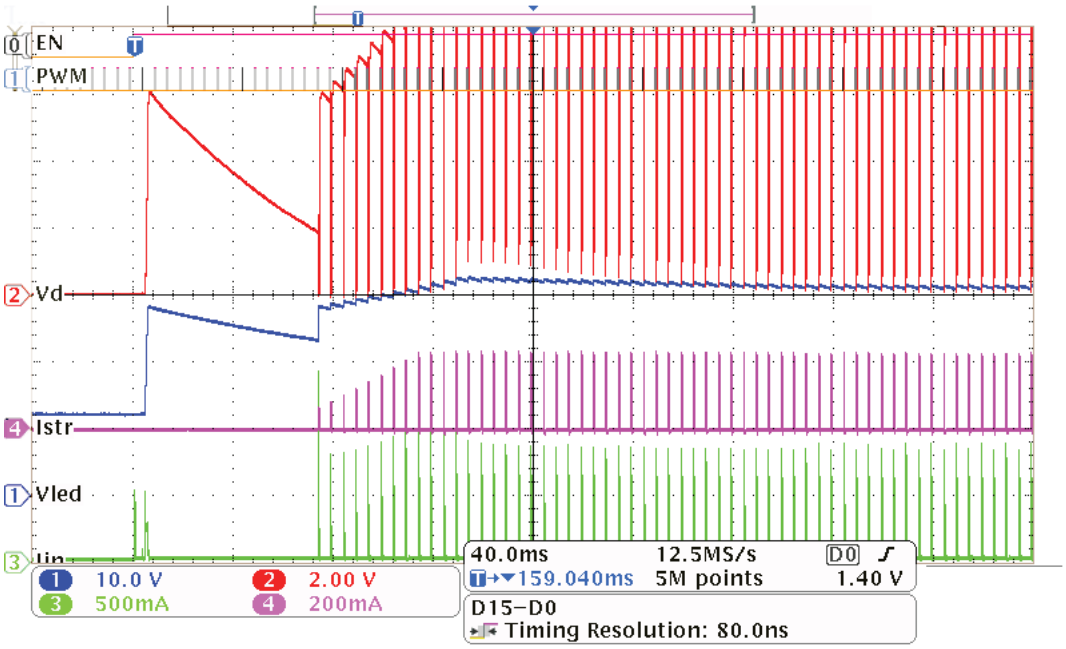


Figure 6-4. Start-up behavior, PWM = 10% (Zoom) duty cycle (Test conditions).

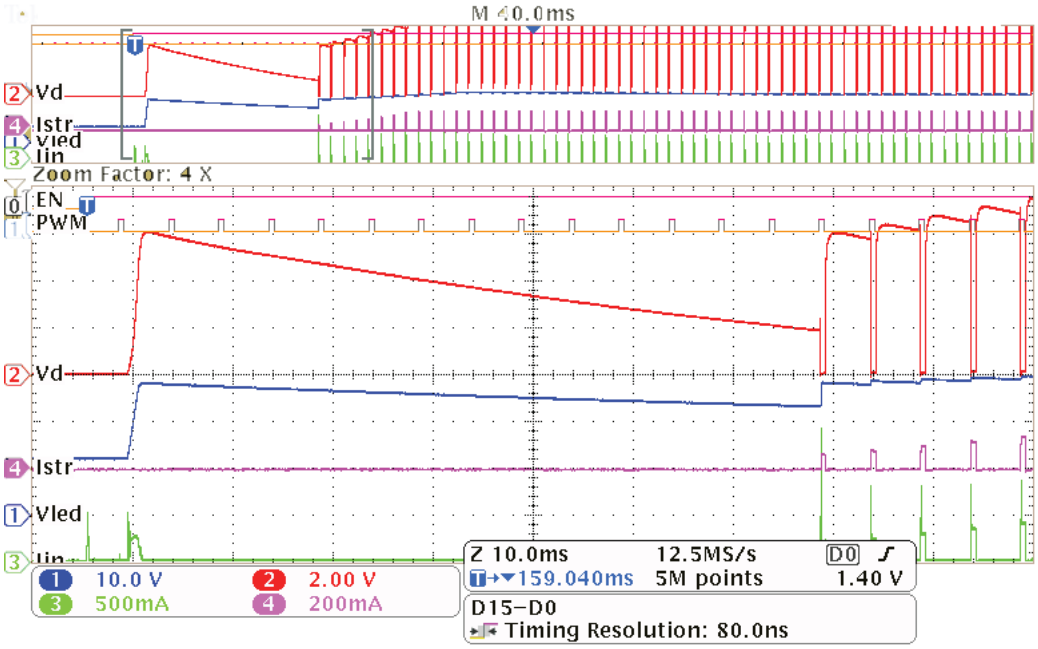


Figure 6-5. Start-up behavior, PWM = 90% duty cycle (Test conditions).

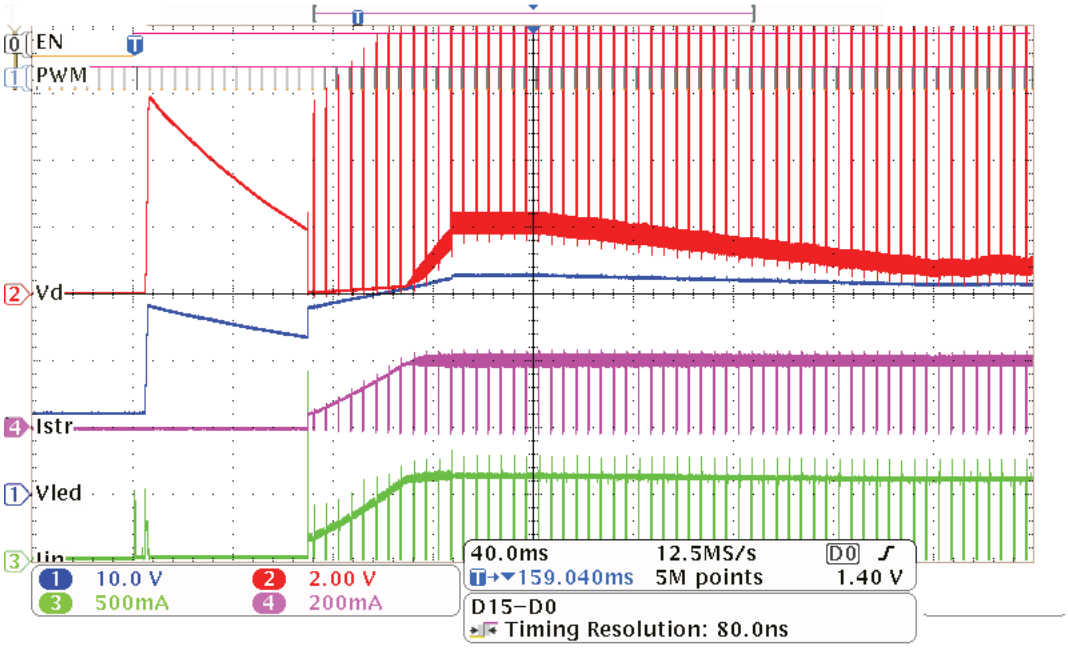


Figure 6-6. Start-up behavior,, PWM = 90%(zoom) duty cycle (Test conditions).

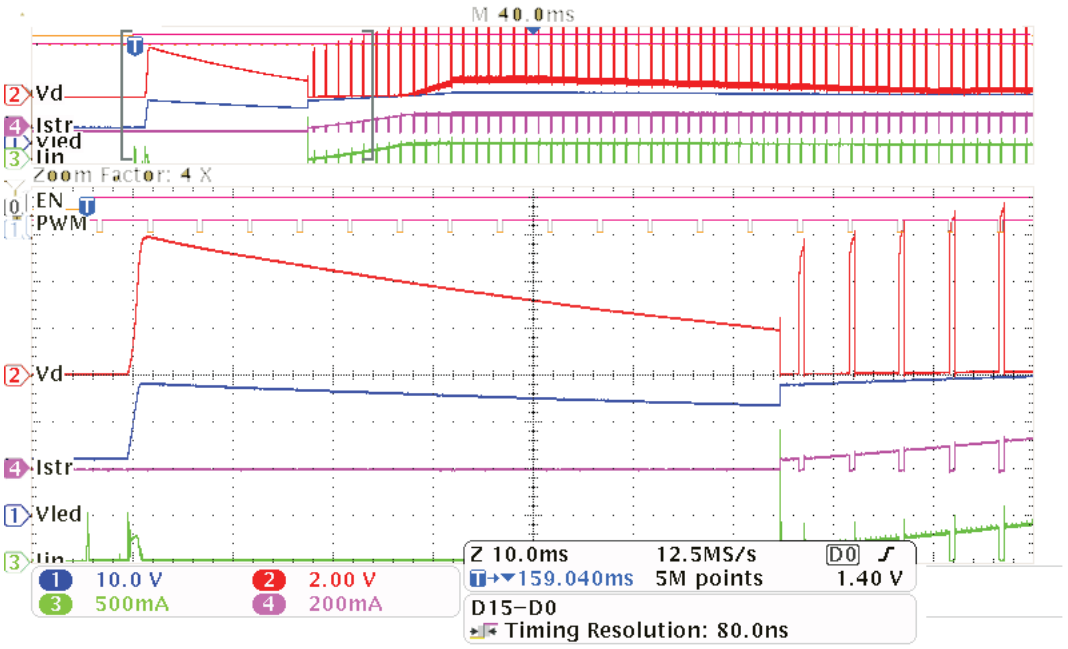


Figure 6-7. Operating current vs. input voltage

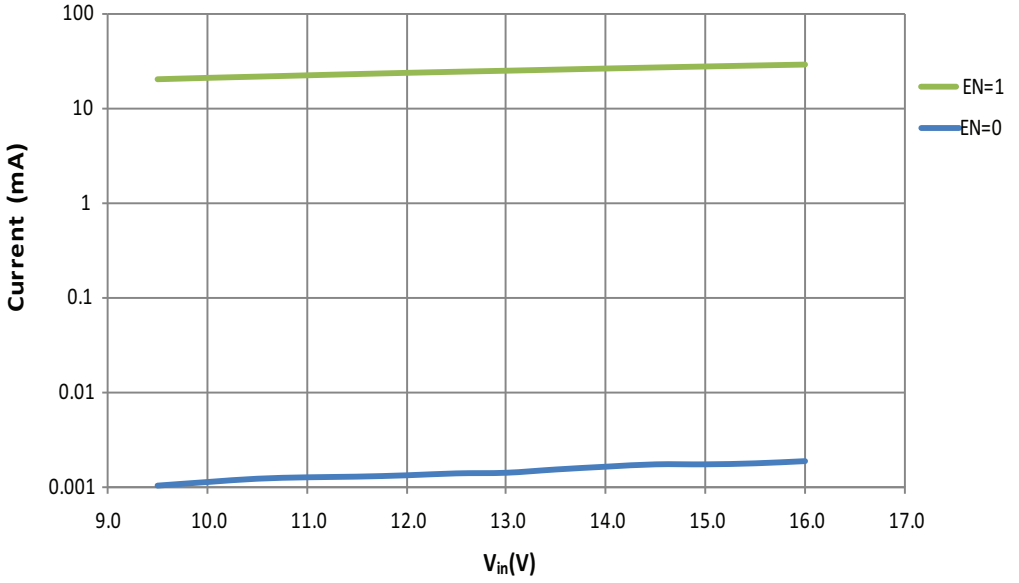


Figure 6-8. V_{CC} and V_{DD} regulation

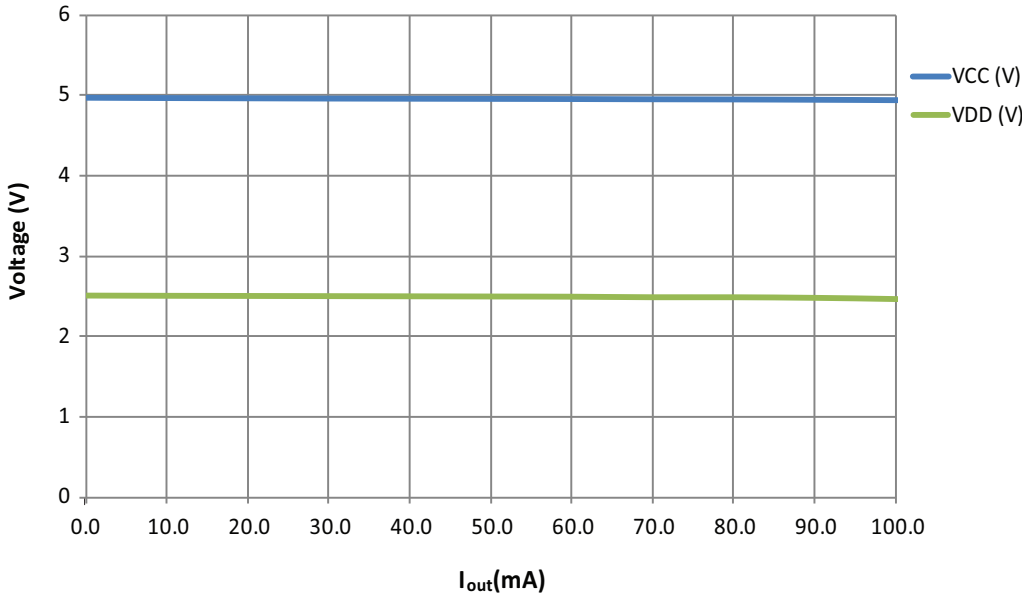
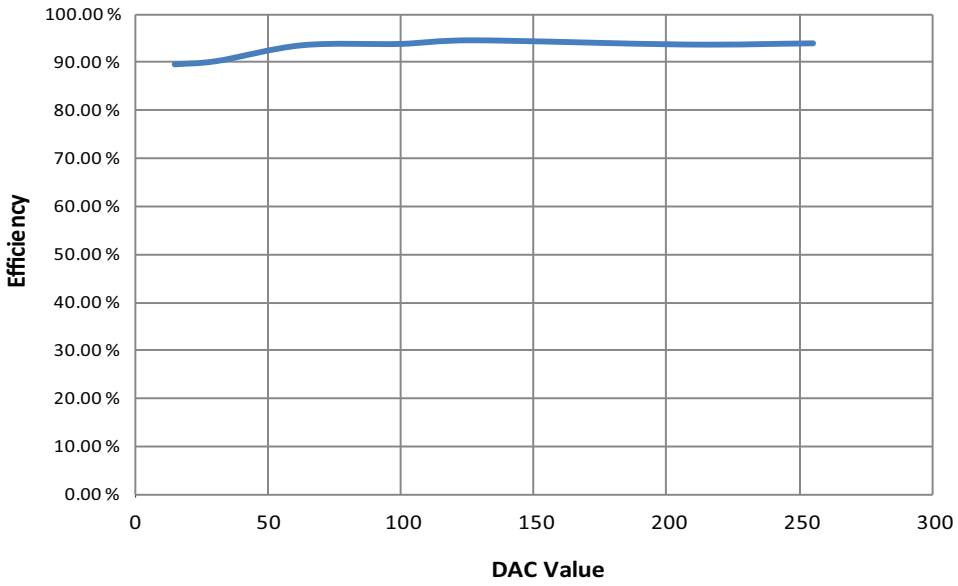
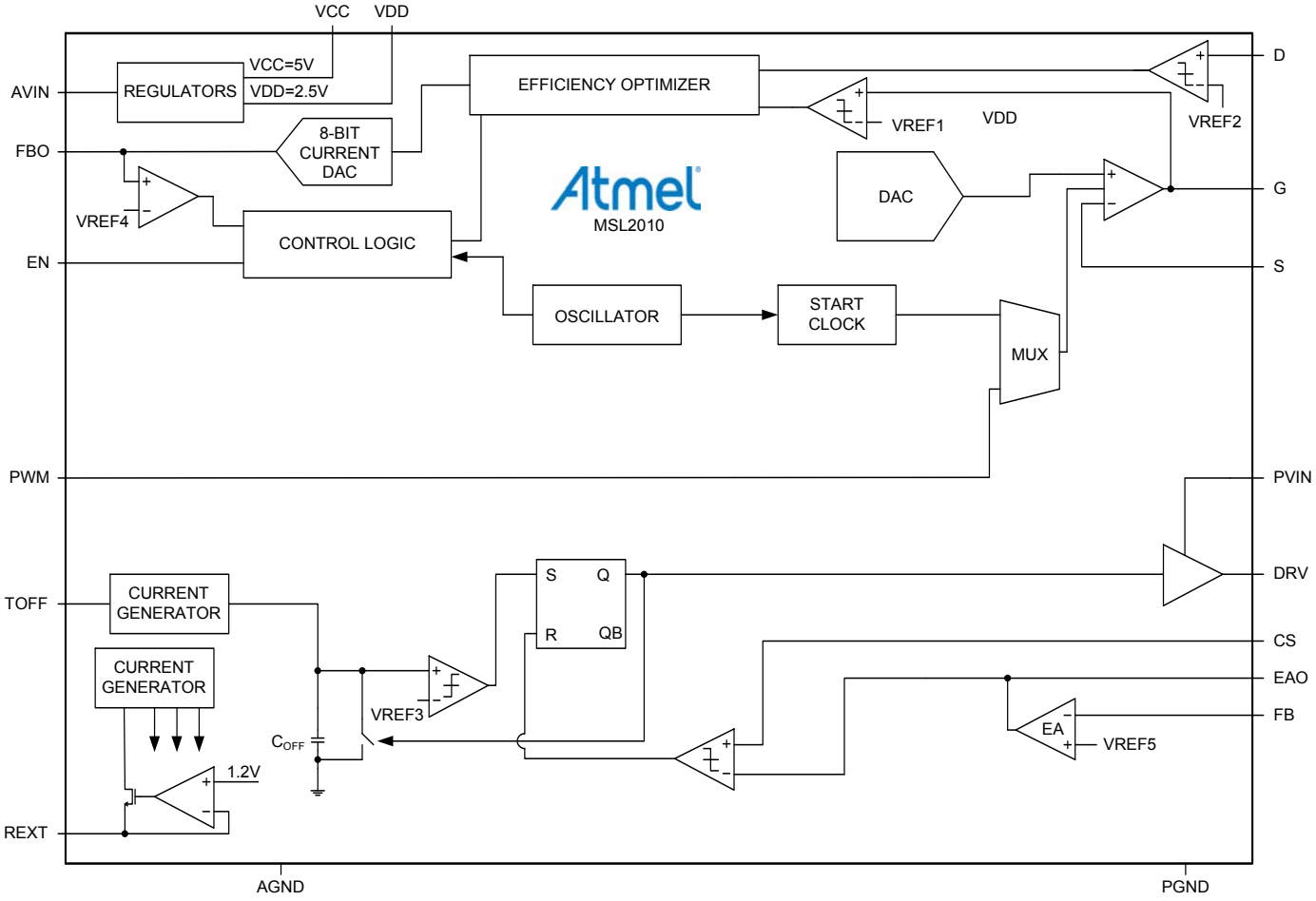


Figure 6-9. Efficiency vs DAC value



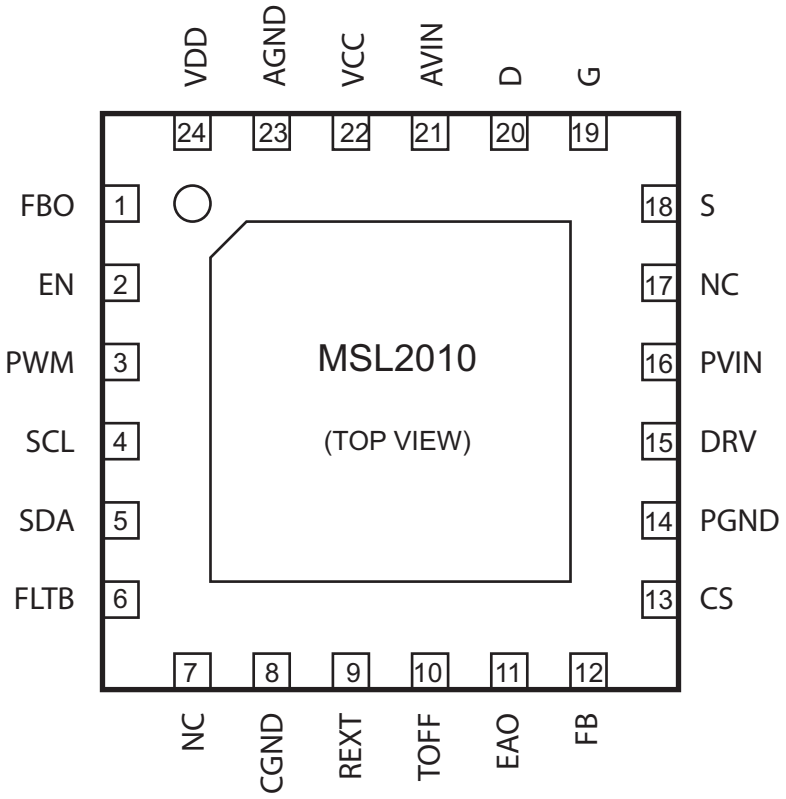
7. Block Diagram

Figure 7-1. MSL2010 block diagram



8. Pinout and Pin Description

8.1 Pinout MSL2010



8.2 Pin Descriptions

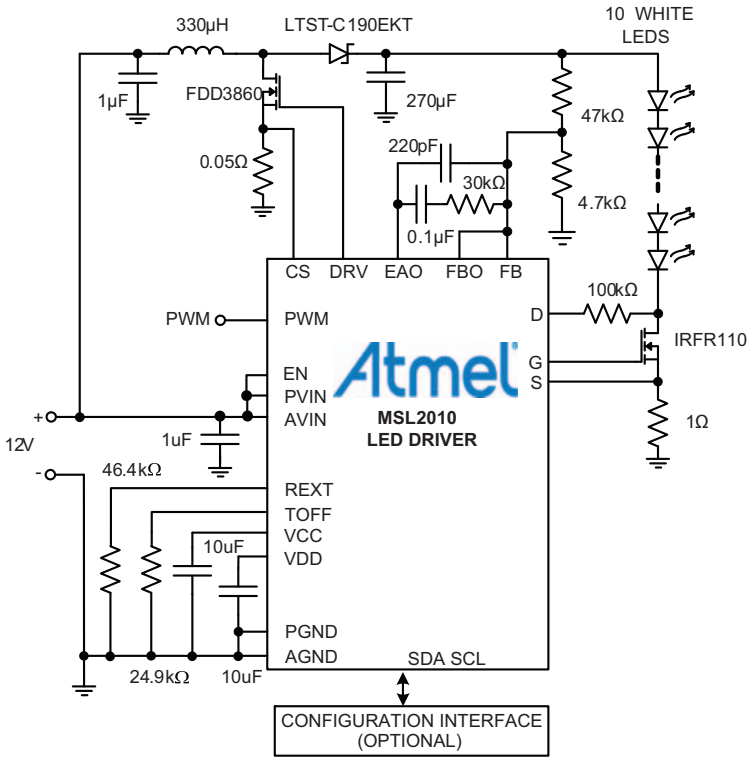
Name	Pin	Description
FBO	1	**Feedback Output** Feedback output from Efficiency Optimizer. Connect FBO to the LED power supply regulation feedback node to control V_{LED}. When unused connect FBO to VCC.
EN	2	**Enable Input (Active High)** Drive EN high to turn on the MSL2010, drive EN low to turn it off. For automatic start-up connect EN to AVIN.
PWM	3	**PWM Dimming Input** Drive PWM with a pulse-width modulated signal to control LED brightness. See “PWM and LED Brightness” on page 17 for details.
SCL	4	**Serial Clock Input** SCL is the I²C serial interface clock input. See “I²C Serial Interface” on page 21 details.
SDA	5	**Serial Data Input/Output** SDA is the I²C serial interface data I/O. See “I²C Serial Interface” on page 21 details.
FLTB	6	**Fault Output** Open Collector FLTB pulls low when an overtemperature is detected (die temperature≥147°C). FLTB releases when the die temperature falls below 127°C.
NC	7, 17	**No Internal Connection**

Name	Pin	Description
CGND	8	**Connect to Ground** Connect CGND to AGND
REXT	9	**External Resistor** Connect a 46.4kΩ, 1% resistor from REXT to AGND.
TOFF	10	**Off-Time Set Input** A resistor from TOFF to AGND controls the constant off time for the Boost converter, where $R_{TOFF} = t_{OFF} * (90.9 \times 10^9)$, with t_{OFF} in seconds and R_{TOFF} in Ohms. For example, an off time of 4.4µs results in a resistor value of 402kΩ (to the nearest 1% value).
EAO	11	Error Amp Out Output of the switch-mode error amplifier. Connect the compensation network between EAO and FB.
FB	12	**Feedback Input for Boost Regulator** Connect FB to the middle node of the Boost regulator voltage setting resistor divider. Also, connect FBO to FB to allow the MSL2010 to optimize V_{LED}.
CS	13	**Current Sense Input for the Boost Converter** Connect CS to the external current sense resistor of the Boost regulator. The current sense threshold is 200mV. For more information see the section “Boost Reference Voltage register (CSREF, 0x21)” on page 20.
PGND	14	Power Ground PGND is the ground connection for the FET gate drivers. Connect PGND to AGDN close to the MSL2010.
DRV	15	**Gate Drive for Boost Regulator MOSFET** Connect DRV to the gate of the Boost regulator power MOSFET.
PVIN	16	**Power Voltage Input** PVIN powers DRV, the Boost regulator FET gate driver. Connect PVIN to a power supply of 10V to 15V. Bypass PVIN to PGND with a 1.0µF or greater capacitor.
S	18	**Source Sense Input for LED String Drive MOSFET** Connect S to the source of the LED string drive external MOSFET, and to the current sense resistor for the LED string. The current sense threshold is 200mV. For more information see the section “LED String Reference Voltage register (SREF, 0x20)” on page 20.
G	19	**Gate Output for LED String MOSFET** Connect G to the gate of the LED string drive external MOSFET. Minimum on-time is 2µs.
D	20	**Drain Output for LED String MOSFET** Connect D to the drain of the LED string drive external MOSFET.
AVIN	21	**Analog Voltage Input (12V)** AVIN is the power input to the MSL2010. Bypass AVIN to AGND with a 1.0µF or greater capacitor placed close to AVIN.
VCC	22	5V Internal Voltage Connect 10µF bypass capacitor from VCC to AGND.
AGND	23	Analog Ground Connect AGND to system ground.
VDD	24	**2.5V Internal Voltage** Connect 10uF bypass capacitor from VDD to AGND.
EP	EP	**Exposed Pad** EP is the main thermal path for heat to escape the die. Connect EP to a large copper plane connected to PGND and AGND.

9. Typical Application Circuit

MSL2010 Boost Switcher and Linear Driver, Driving 10 White LEDs.

Figure 9-1. Typical application circuit



10. Detailed Description

The MSL2010 drives one LED string, and includes a Boost Regulator Controller to generate V_{LED}, the string voltage, from a low voltage input. An Efficiency Optimizer (EO) algorithm regulates V_{LED} to the minimum required to keep the LEDs in current regulation, minimizing power loss across the external string drive MOSFET. A PWM input accepts 1% to 100% duty cycle signal of 60Hz to 10kHz. The LED PWM output dimming duty cycle and frequency equal the PWM input duty cycle and frequency, with a 2µs minimum on time. LEDs are driven by a linear driver.

11. Fault Conditions

Over Temperature Protection shuts down the device when the die temperature is above 133°C. The device turns back on when the die temperature falls below 118°C, as if EN is taken from low to high.

12. Applications Information

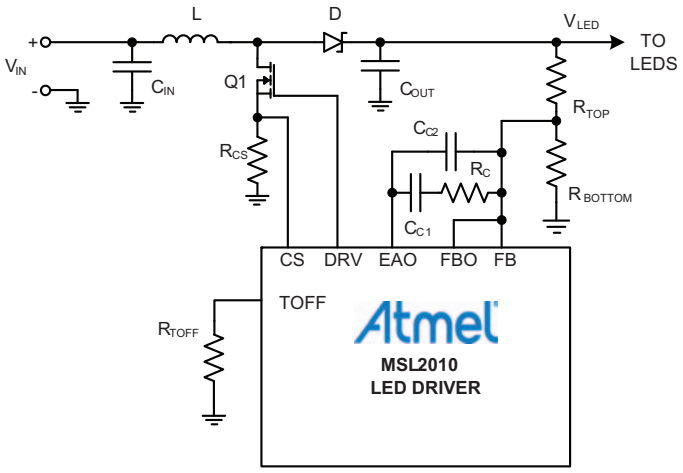
12.1 Turn-On Sequence

When EN is taken high, the MSL2010 waits for 6ms, then optimizes V_{LED}, the LED string voltage, which typically takes about 250ms, then begins to drive the LEDs based on the PWM input.

12.2 The Boost Regulator

MSL2010 includes a Constant Off-Time DC/DC Boost Controller to generate V_{LED}, the voltage for the LED string. The Boost components are shown in Figure 12-1 on page 15, and include a voltage setting resistor divider, a MOSFET, a Schottky diode, a resistor to set the Off-Time, an Inductor, a current sense resistor, a Drain resistor, a few capacitors and a compensation network. The following sections discuss selecting these components.

Figure 12-1. Boost Regulator Components



12.2.1 Setting the Boost Output Voltage, V_{LED}

A resistor divider sets the nominal Boost output voltage, V_{LED}. Select the two feedback resistors by first determining the minimum output voltage using:

$$V_{OUT(MIN)} \le (V_{fMIN}) * (N) + 0.2 \text{ V},$$

where V_{fMIN} is the minimum LED forward voltage at the expected LED current, N is the number of LEDs in the string, and 0.2V is the minimum overhead required for the current sense resistor and the FET. Then determine the maximum output voltage using:

$$V_{OUT(MAX)} = (V_{fMAX}) * (N) + 1.2 \text{ V},$$

where V_{fMAX} is the maximum LED forward voltage at the expected LED current, N is the number of LEDs in the string, and 1.2V is the maximum overhead required for the current sense resistor and the FET.

Determine the value for the upper voltage setting resistor using:

$$R_{TOP} = \frac{V_{OUT(MAX)} - V_{OUT(MIN)}}{340 \times 10^{-6}} \Omega,$$

where 340µA is the guaranteed maximum FBO current from the "Electrical Characteristics" on page 4. Determine the lower resistor using:

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

where 2.5V is V_{FB}, the feedback regulation voltage of the FB input. The Efficiency Optimizer (EO) output, FBO, connects to FB and pulls current from the node to force the converter's output voltage up to the proper level to keep the LEDs in current regulation with the minimum power loss.

12.2.2 The Boost MOSFET and Schottky Diode

Output DRV drives the gate of an external N-Channel MOSFET at up to V_{PVIN} – 1.5V. Select a MOSFET with a maximum drain-source voltage of at least 1V above $V_{OUT(MAX)}$ (from above), a low gate charge and low $R_{DS(ON)}$. Use a Schottky diode with a maximum reverse voltage of at least $V_{OUT(MAX)}$.

12.2.3 The Off-Time Resistor, R_{TOFF}

The Boost driver uses a constant off-time algorithm. The MOSFET turns off when V_{CS} = 0.2V (Figure 12-1 on page 15). Control off-time with external resistor R_{TOFF} using:

$$R_{TOFF} = t_{OFF} * \left(90.9 \times 10^{9}\right)\Omega,$$

where t_{OFF} is in seconds. For example, an off-time of 4.4µs results in a resistor value of 402kΩ (to the nearest 1% value).

12.2.4 Setting the Inductor Current with R_{CS}

The Boost inductor peak current regulates by way of the voltage at CS, the Boost MOSFET source resistor connection. Connect the current sense resistor R_{CS} from the MOSFET source to ground. The default feedback voltage for CS is 0.2V. Choose the current sense resistor using:

$$R_{CS} = \frac{0.2}{I_L}\Omega,$$

where I_L is the inductor peak current. For example, for 350mA I_L, use R_{CS} of 0.56 Ohms. The 0.2V in this equation is set in the Current Sense Reference Voltage (CSREF) register 0x21. The default value for CSREF is 0x64, which sets the feedback voltage to 0.2V. For information about CSREF see "Boost Reference Voltage register (CSREF, 0x21)" on page 20.

12.2.5 Sizing The Inductor, L

Current increases through the inductor until the voltage at CS reaches 0.2V. The MOSFET then turns off for the off-time programmed by R_{TOFF} (above). Estimate the inductor value using:

$$L = \frac{v(t)}{\left(di(t)/dt\right)}\text{H},$$

where v(t) = the acceptable ripple voltage of V_{LED}, di(t) = acceptable peak to peak inductor ripple current, and dt = the off-time set by R_{TOFF}.

For example:

With an inductor ripple voltage of 0.5% of $V_{OUT(MAX)}$ (from above), v(t) = 35.2 ∗ (0.005) = 176mV.

With an average load current of 350mA and an inductor ripple current of 4%, di(t) = 0.35 ∗ 0.04 = 0.014A.

And, with a t_{OFF} of 4.4µs, then:

$$L = \frac{0.176}{\left(0.014/4.4 \times 10^{-6}\right)} = 55\mu H.$$

Assure that the inductor saturation current rating is greater than I_L, the peak inductor current from the R_{CS} equation above.

12.2.6 The Drain Resistor, R_D

The drain resistor, R_D in Figure 12-1 on page 15, connects the MSL2010 to the Drain of the LED string external MOSFET. Use a 100kΩ for R_D.

12.2.7 The Input and Output Capacitors

The input and output capacitors carry the high frequency current of 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 capacitors that keep their rated values at their expected operating voltages. The "Typical Application Circuit" on page 14 shows recommended values for these capacitors.

12.2.8 The Compensation Network

The compensation components, R_C, C_{C1} and C_{C2} in Figure 12-1 on page 15, effectively dampen the oscillation-producing high frequency response of the Boost regulator error amplifier. The "Typical Application Circuit" on page 14 shows recommended values for these capacitors.

12.3 The LED string

12.3.1 Selecting the LED String MOSFET

The LED string MOSFET sinks the LED current to ground through current sense resistor R_S. Output G drives the gate of the MOSFET with at up to at least V_{AVIN} – 1.5V. Select a FET with a maximum drain-source voltage of at least $V_{OUT(MAX)}$ (from above), and a low $R_{DS(ON)}$.

12.3.2 Setting LED String On-Current with R_S

The LED string on-current regulates by monitoring the voltage at S, the MOSFET source resistor connection. Connect the current sense resistor R_S from the MOSFET source to ground. The default feedback voltage for S is 0.2V. Choose the string current sense resistor R_S using:

$$R_S = \frac{0.2}{I_{LED}}\Omega,$$

where I_{LED} is the LED string regulation current. The LED String Reference Voltage (SREF), register 0x20, sets the 0.2V feedback voltage, at 2mV per LSB. For more information about SREF see the "LED String Reference Voltage register (SREF, 0x20)" on page 20.

12.3.3 PWM and LED Brightness

MSL2010 uses the input signal at PWM to directly control the duty cycle (brightness) and frequency of the LED string driver output G. The PWM input accepts a signal of 60Hz to 10kHz, 1% to 100% duty cycle; output G operates with a minimum on time of 2µs.

13. Control Registers

Table 13-1. MSL2010 Register Map (Do not change unspecified registers or bits).

Address and Register name		Function	Default value	Bit functions							
				D7	D6	D5	D4	D3	D2	D1	D0
Control and Monitor Registers											
0x00 through 0x1F		RAM	0xXX	Free RAM							
0x20	SREF	LED String MOSFET Source Feedback Reference Voltage	0x64	S_{REF} = 2mV per LSB							
0x21	CSREF	Boost Current Sense Reference Feedback Voltage	0x64	CS_{REF} = 2mV per LSB							
0x40	EOCTRL	Efficiency Optimizer	0xE5	Reserved[4:0]				DThresh[3:0]			
0x60	E2ADDR	EEPROM Address	0x00	–	EEPROM Address Pointer						
0x61	E2CTRL	EEPROM Control	0x00	–	–	–	–	–	RWCTRL[2:0]		
Unused and Reserved Registers											

13.1 EEPROM and Power-Up Defaults

An on-chip EEPROM holds all the default register values (Table 13-1 on page 18). At power-up the data in the EEPROM automatically copy directly to control registers 0x00 thru 0x51, setting up the device for operation.

Any changes made to registers 0x00 thru 0x51 after power-up are not reflected in the EEPROM and are lost when power is removed from the device, or when the enable input EN is forced low. If a different power-up condition is desired program the values into the EEPROM via the serial interface as explained in the next section, or contact the factory to inquire about ordering a customized power-up setting.

13.2 EEPROM Address and Control/Status Registers

The EEPROM can be visualized as an image of the control registers from 0x00 thru 0x69. Change an EEPROM register value by writing the new value into the associated control register, and then instructing the device to program that value into the EEPROM. Two control registers facilitate this process, the EEPROM address register E2ADDR (0x60), and the EEPROM control register E2CTRL (0x61). Into E2ADDR write the location of the data that is to be programmed into the EEPROM, and write 0x03 to E2CTRL to command the device to program that data into the EEPROM. Programming the EEPROM takes a finite amount of time; after sending a command to E2CTRL wait 5ms, then end the write cycle by writing 0x00 to E2CTRL.

Example: Change the string current feedback voltage MREF to 100mV.

Commands: To register 0x20 (MREF) write 0x32 (the new value for MREF). To register 0x60 (E2ADDR) write 0x20 (the address of the MREF register). To register 0x61 (E2CTRL) write 0x03 (the command to copy the value to EEPROM). Wait 5ms. To register 0x61 (E2CTRL) write 0x00, to turn off EEPROM access.

Result: The value 0x32, located in the MREF register, is programmed into the EEPROM and becomes the new power-up default value for MREF.

Summary:

0x20 32

0x60 20

0x61 03

Wait 5ms

0x61 00

E2CTRL provides additional functions beyond simply programming a register's value into the EEPROM. Data may be transferred in either direction, from the registers to the EEPROM, or from the EEPROM to the registers. Register data may be transferred into or out of the EEPROM in groups of eight, a page at a time. The page address boundaries are predefined, and E2ADDR must be loaded with the address of the first byte of the page that is to be copied. Page addresses begin at 0x00 and increment by eight, with the second page beginning at 0x08, the third at 0x10, etc. To program a full page of data into the EEPROM, write the address of the page's first byte to E2ADDR, and write 0x04 to E2CTRL. Wait 5ms, and then end the write cycle by writing 0x00 to E2CTRL. When finished accessing the EEPROM always write 0x00 to E2CTRL to block inadvertent EEPROM read/writes. Table 13-2 on page 19 details the functions available through E2CTRL.

Table 13-2. EEPROM Address Register (E2ADDR, 0x60), defaults highlighted.

Register	Address	Register data							
		D7	D6	D5	D4	D3	D2	D1	D0
E2ADDR	0x60	-	E2ADDR[6:0]						
DEFAULT		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
EEPROM Minimum Address 0x00		-	0	0	0	0	0	0	0
EEPROM Maximum Address 0x51		-	1	0	1	0	0	0	1

Table 13-3. EEPROM Status Register (E2CTRL, 0x61), defaults highlighted.

Register	Address	Register data							
		D7	D6	D5	D4	D3	D2	D1	D0
E2CTRL	0x61	-	-	-	-	-	RWCTRL[2:0]		
DEFAULT		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
EEPROM Read / Write Disabled		x	x	x	x	x	**0**	**0**	**0**
Read 1 Byte from EEPROM		x	x	x	x	x	0	0	1
Read 8 Bytes from EEPROM		x	x	x	x	x	0	1	0
Write 1 Byte to EEPROM		x	x	x	x	x	0	1	1
Write 8 Bytes to EEPROM		x	x	x	x	x	1	0	0
Unused		x	x	x	x	x	1	0	1
		x	x	x	x	x	1	1	x

14. Detailed Register Descriptions

The MSL2010 registers are summarized in “Control Registers” on page 18. Detailed register information follows.

14.1 RAM (0x00 through 0x1F)

32 Bytes of RAM accessible through the I^2C serial interface. Copy data from RAM into EEPROM (see *“EEPROM and Power-Up Defaults” on page 18*) to have the data automatically load into the RAM at power up, and when EN is taken high.

Table 14-1. RAM (0x00 through 0x1F), defaults undetermined

		REGISTER DATA							
REGISTER NAME	ADDRESS	D7	D6	D5	D4	D3	D2	D1	D0
DEFAULTS		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**

14.2 LED String Reference Voltage register (SREF, 0x20)

Holds the DAC value that controls the reference voltage for the LED string MOSFET source feedback. The reference voltage equals decimal value of this register times 2mV. The default value for SREF is 0x64, which equates to V_{SREF} = 200mV.

Table 14-2. LED String Reference register (SREF, 0x20), defaults **highlighted**

		REGISTER DATA							
REGISTER NAME	ADDRESS	D7	D6	D5	D4	D3	D2	D1	D0
SREF	0x20	SREF[7:0]							
DEFAULT: V_{SREF} = 0x64 = 100 ∗ 2mV = 200mV		**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**
V_{SREF} = 0 ∗ 2mV = 0V		0	0	0	0	0	0	0	0
V_{SREF} = 255 ∗ 2mV = 510mV		1	1	1	1	1	1	1	1

14.3 Boost Reference Voltage register (CSREF, 0x21)

Holds the DAC value that controls the reference voltage for the Boost MOSFET source feedback. The reference voltage equals decimal value of this register times 2mV. The default value for CSREF is 0x64, which equates to V_{CSREF} = 200mV.

Table 14-3. Boost Reference Voltage register (CSREF, 0x21), defaults **highlighted**

		REGISTER DATA							
REGISTER NAME	ADDRESS	D7	D6	D5	D4	D3	D2	D1	D0
CSREF	0x21	CSREF[7:0]							
DEFAULT: V_{CSREF} = 0x64 = 100 ∗ 2mV = 200mV		**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**
V_{CSREF} = 0 ∗ 2mV = 0mV		0	0	0	0	0	0	0	0
V_{CSREF} = 255 ∗ 2mV = 510mV		1	1	1	1	1	1	1	1

14.4 Efficiency Optimizer Control Register (EOCTRL, 0x40)

DThresh sets the voltage feedback threshold for D, The LED string MOSFET drain connection.

D Threshold = (<DThresh> ∗ 150mV) + 250mV. This is how the device monitors V_{LED} to control the magnitude of the EO current. The default value for DThresh is 1V.

Table 14-4. Efficiency Optimizer Control Register (FBOCTRL, 0x40), default **highlighted**

Register	Address/ Default	Register data							
		D7	D6	D5	D4	D3	D2	D1	D0
FBOCTRL	0x40	Reserved[4:0]				DThresh[3:0]			
Defaults	**0xE5**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**1**
D Threshold = (0 ∗ 150mV) + 250mV = 0.25V		1	1	1	0	0	0	0	0
D Threshold = (5 ∗ 150mV) + 250mV = 1V		**1**	**1**	**1**	**0**	**0**	**1**	**0**	**1**
D Threshold = (15 ∗ 150mV) + 250mV = 2.5V		1	1	1	0	1	1	1	1

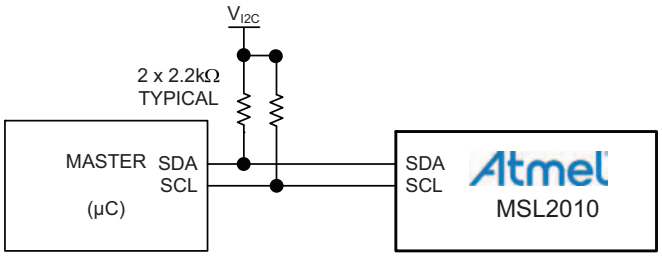
These registers control access to the EEPROM. See *"EEPROM and Power-Up Defaults" on page 18* and *"EEPROM Address and Control/Status Registers" on page 18* for information.

15. I²C Serial Interface

The MSL2010 operates as a slave that sends and receives data through an I²C/SMBus compatible 2-wire serial interface. The interface is not needed for operation, but is provided to allow control and monitoring of device functions. These functions include changing the string current reference feedback voltages, reading and adjusting the fault response behavior and status, and programming the EEPROM. The I²C/SMBus compatible interface is suitable for 100kHz, 400kHz and 1MHz communication. The interface uses data I/O SDA and clock input SCL to achieve bidirectional communication between master and slaves.

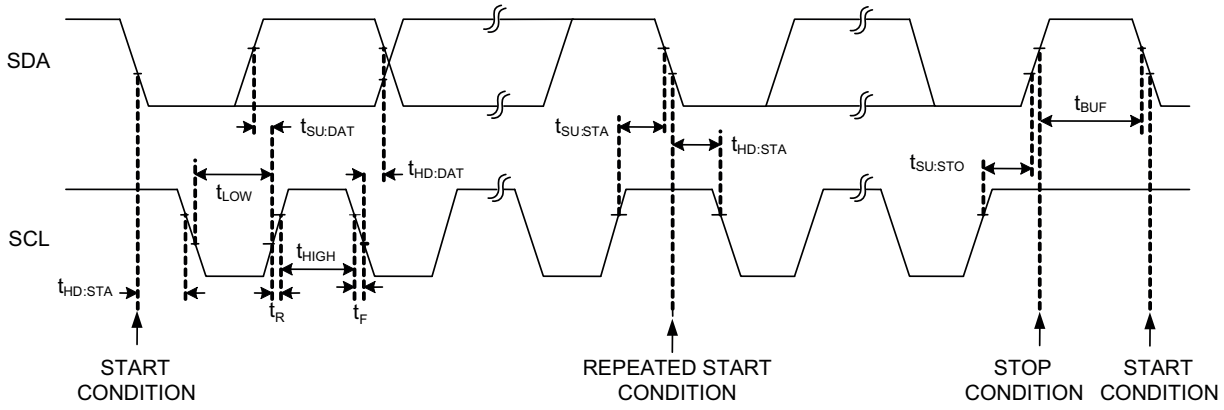
The master, typically a microcontroller, initiates all data transfers, and generates the clock that synchronizes the transfers. SDA operates as both an input and an open-drain output. SCL operates only as an input, and does not perform clock-stretching. Pull-up resistors are required on SDA, and SCL.

Figure 15-1. I²C Interface Connections



A transmission consists of a START condition sent by a master, a 7-bit slave address plus one R/W bit, an acknowledge bit, none or many data bytes each separated by an acknowledge bit, and a STOP condition (Figure 15-2, Figure 15-4 and Figure 15-5 on page 23).

Figure 15-2. I²C Serial Interface Timing Details



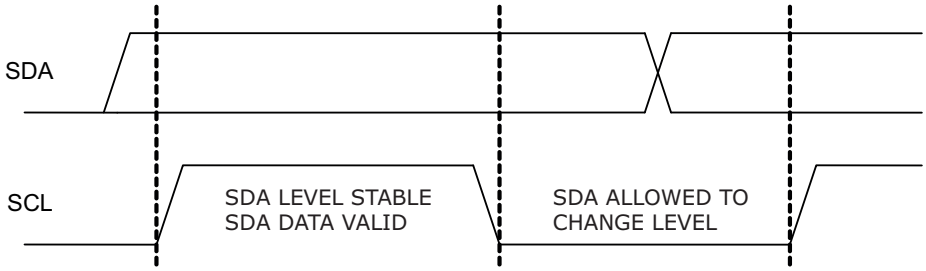
15.1 I²C Bus Timeout

The bus timeout feature allows the MSL2010 to reset the serial bus interface if a communication ceases before a STOP condition is sent. If SCL or SDA is low for more than 25ms (typical), then the MSL2010 terminates the transaction, releases SDA and waits for another START condition.

15.2 I²C Bit Transfer

One data bit is transferred during each clock pulse. SDA must remain stable while SCL is high.

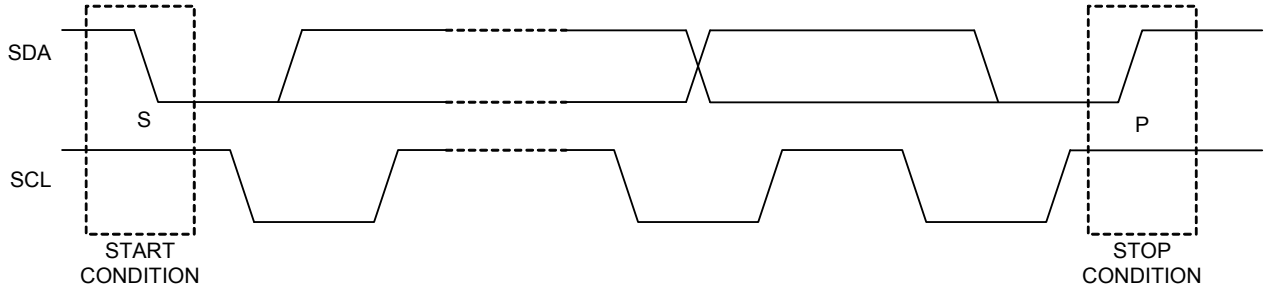
Figure 15-3. I²C Bit Transfer



15.3 I²C START and STOP Conditions

Both SCL and SDA remain high when the interface is free. The master signals a transmission with a START condition (S) by transitioning SDA from high to low while SCL is high. When the master has finished communicating with the slave, it issues a STOP condition (P) by transitioning SDA from low to high while SCL is high. The bus is then free.

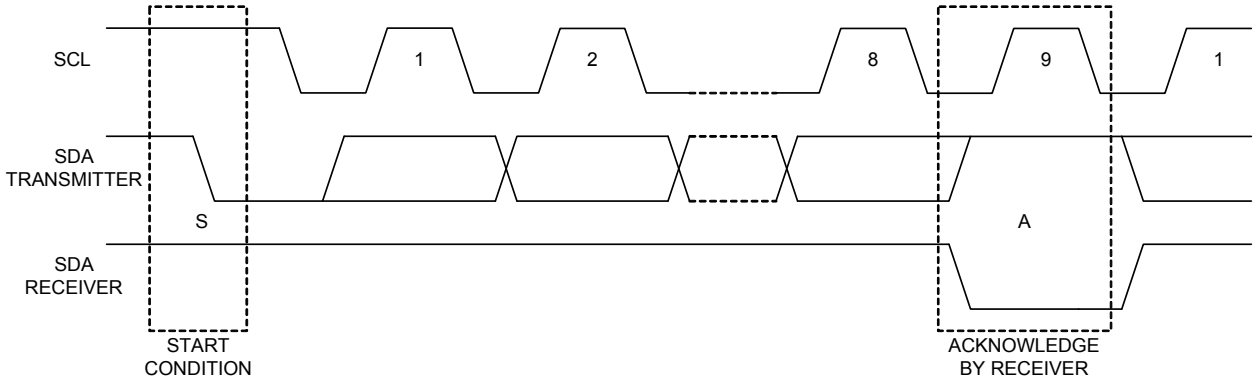
Figure 15-4. I²C START and STOP Conditions



15.4 I²C Acknowledge Bit

The acknowledge bit is a clocked 9th bit which the recipient uses to handshake receipt of each byte of data. The master generates the 9th clock pulse, and the recipient holds SDA low during the high period of the clock pulse. When the master is transmitting to the MSL2010, the MSL2010 pulls SDA low because the MSL2010 is the recipient. When the MSL2010 is transmitting to the master, the master pulls SDA low because the master is the recipient.

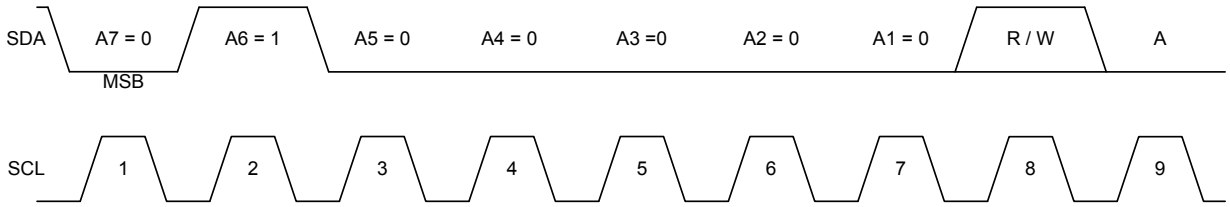
Figure 15-5. I²C Acknowledge



15.5 I²C Slave Address

The MSL2021 has a 7-bit long slave address, 0b0100000, followed by an eighth bit, the R/W bit. The R/W bit is low for a write to the MSL2010, high for a read from the MSL2010. All MSL2010 devices have the same slave address; when using multiple devices and communicating with them through their serial interfaces, make external provision to route the serial interface to the appropriate device. Note that development systems that use I²C often left-shift the address one position before they insert the R/W bit, and thus expect a base address setting of 0x20 instead of 0x40.

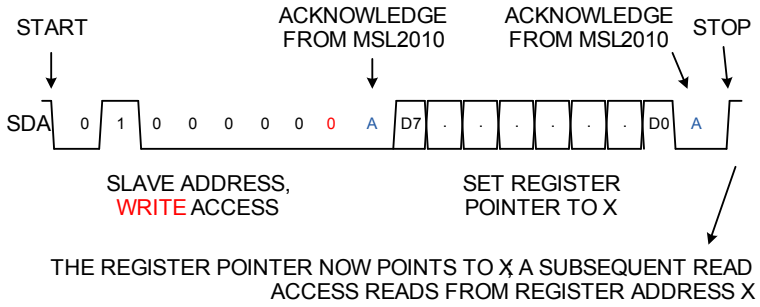
Figure 15-6. I²C Slave Address



15.6 I²C Message Format for Writing to the MSL2010

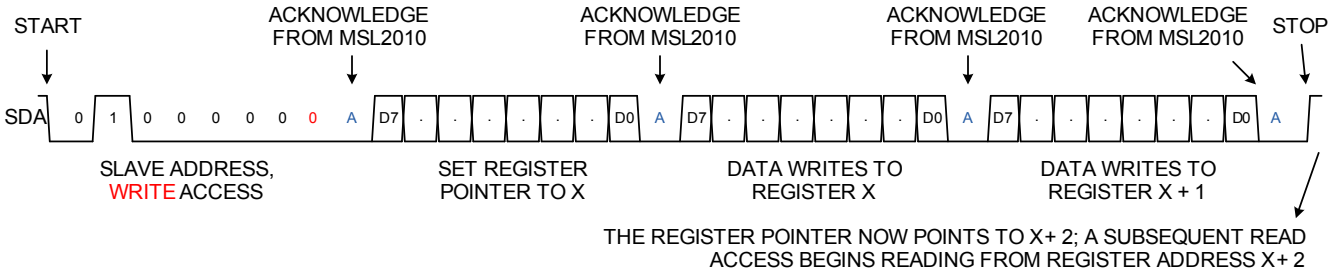
A write to the MSL2010 contains the MSL2010's slave address, the R/W bit cleared to 0, and at least 1 byte of information (Figure 15-7 on page 24). The first byte of information is the register address byte. The register address byte is stored as a register pointer, and determines which register the following byte is written into. If a STOP condition is detected after the register address byte is received, then the MSL2010 takes no further action beyond setting the register pointer.

Figure 15-7. I²C Writing a Register Pointer



When no STOP condition is detected, the byte transmitted after the register address byte is a data byte, and is placed into the register pointed to by the register address byte (Figure 15-8). To simplify writing to multiple consecutive registers, the register pointer auto-increments during each following acknowledge period. Further data bytes transmitted before a STOP condition fill subsequent registers.

Figure 15-8. I²C Writing Two Data Bytes

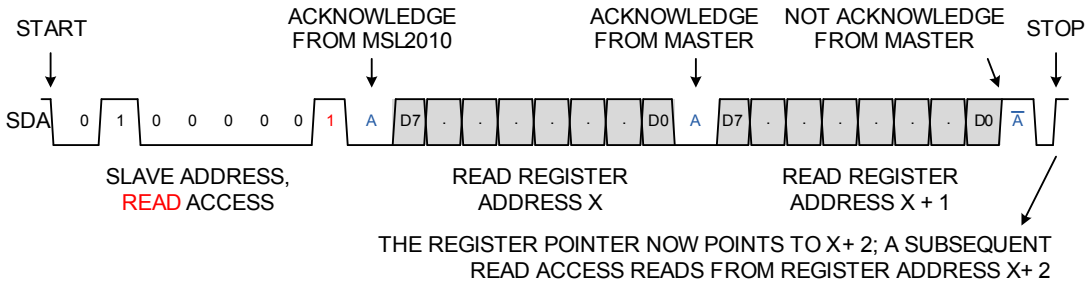


15.7 I²C Message Format for Reading from the MSL2010

Read the MSL2010 registers using one of two techniques.

The first technique begins the same way as a write, by setting the register address pointer as shown in Figure 15-7, including the STOP condition (note that even though the final objective is to read data, the R/W bit is first sent as a write because the address pointer byte is being written into the device). Follow the Figure 15-7 transaction by what shown in Figure 15-9, with a new START condition and the slave address, this time with the R/W bit set to 1 to indicate a read. Then, after the slave initiated acknowledge bit, clock out as many bytes as desired, separated by master initiated acknowledges. The pointer auto-increments during each master initiated acknowledge period. End the transmission with a not-acknowledge followed by a stop condition.

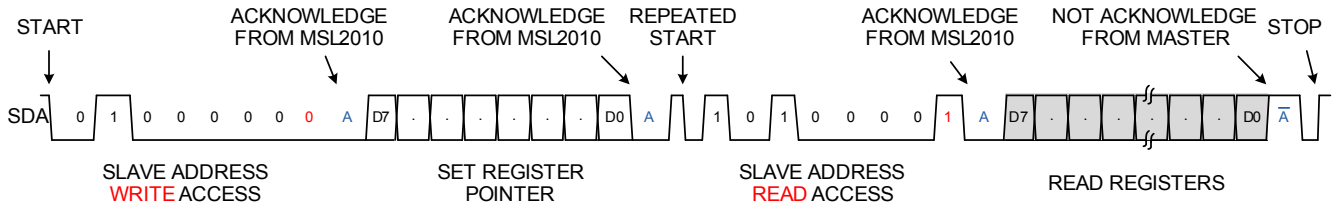
Figure 15-9. I²C Reading Register Data with Preset Register Pointer



The second read technique is illustrated in Figure 15-10. Write to the MSL2010 to set the register pointer, send a repeated START condition after the second acknowledge bit, then send the slave address again with the R/W bit set to 1 to indicate a read. Then clock out the data bytes separated by master initiated acknowledge bits. The register pointer auto-increments during each master initiated acknowledge period. End the transmission with a not-acknowledge

followed by a stop condition. This technique is recommended for buses with multiple masters, because the read sequence is performed in one uninterruptible transaction.

Figure 15-10. I²C Reading Register Data Using a Repeated START

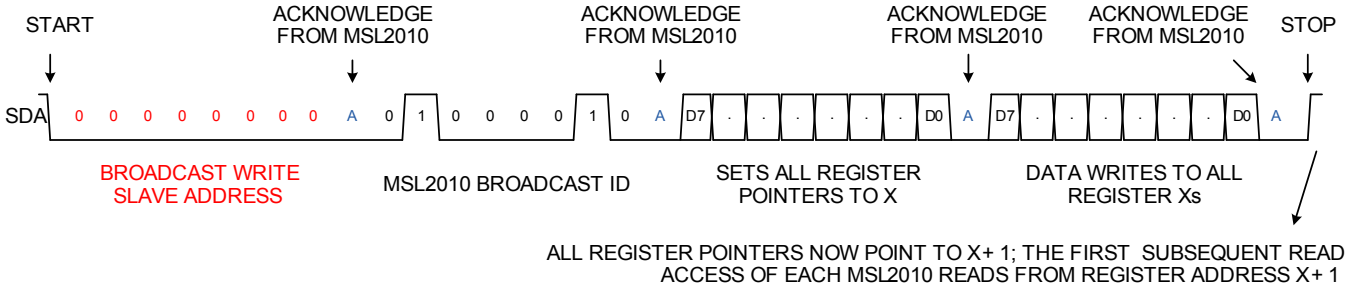


15.8 I²C Message Format for Broadcast Writing to Multiple devices

With a broadcast write to MSL2010, a master broadcasts the same register data to all MSL2010s on the bus. First send the broadcast write slave address of 0x00, followed by the MSL2010 broadcast device ID of 0x42. These two bytes are followed by the register address in the MSL2010's that the following data are to be written into, and finally the data byte(s) to be written into all devices.

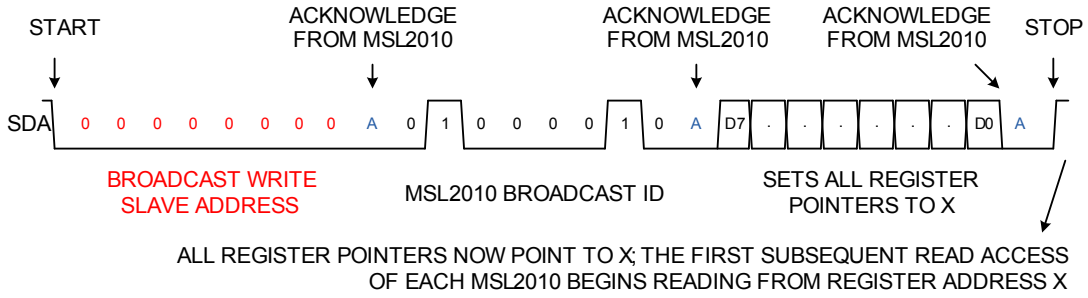
A broadcast write example is shown in Figure 15-11. Here, the same register address in every MSL2010 is written to with identical data. If further data bytes are transmitted before the STOP condition, they are stored in subsequent internal registers of each MSL2010.

Figure 15-11. I²C Broadcast Writing a Data Byte

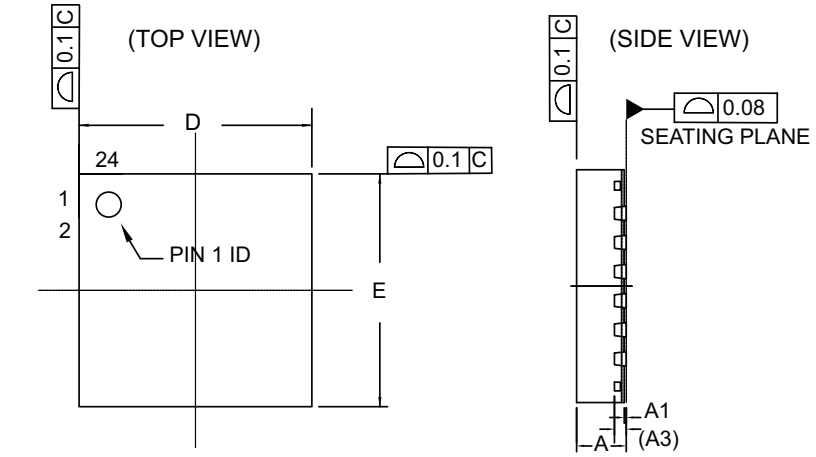


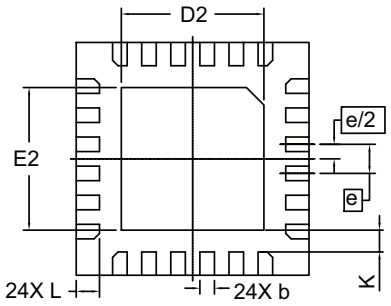
There is no broadcast read. However, a broadcast write may be used to set up the internal register pointers of all the MSL2010s in a system to speed up the subsequent individual reading of, for example, all the status registers. Figure 15-12 illustrates a broadcast write that sets all the register pointers, and issues a STOP.

Figure 15-12. I²C Broadcast Writing a Register Pointer



16. Packaging Information





(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.

1/10/13

Atmel Package Drawing Contact: packagedrawings@atmel.com	TITLE **24M1**, 24-lead, 4.0x4.0x0.9mm Body, 0.50mm Pitch, 2.45mm sq exposed pad, Very Thin Fine Pitch, Quad Flat No Lead Package (VQFN)	GPC ZUH	DRAWING NO. 24M1	REV. B

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17. Datasheet Revision History

17.1 42072A – 05/2013

1.	Initial revision.

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