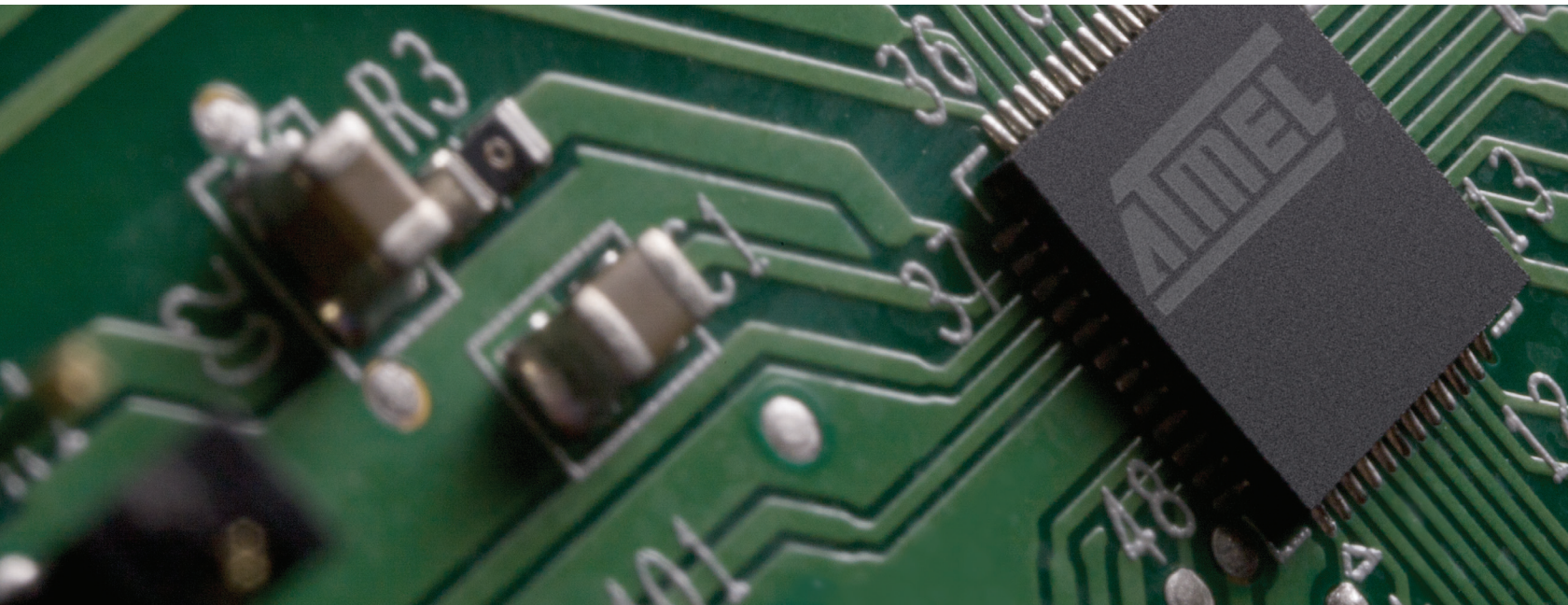




# Atmel LED Driver-MSL2100

8-string, High-power, White or RGB LED Drivers for TVs,  
Monitors, or Intelligent Solid-state Lighting

## Datasheet Brief



# Atmel LED Driver-MSL2100

8-string, High-power, White or RGB LED Drivers for TVs, Monitors, or Intelligent Solid-state Lighting

## General Description

The Atmel® LED Driver MSL2100 compact, high-power LED string driver uses external MOSFETs to provide up to 1A per string, with current accuracy and matching better than  $\pm 1\%$ . The MSL2100 drives eight parallel strings of LEDs, and offers fault detection and management of open and short circuit LEDs.

The MSL2100 features a 1MHz I<sup>2</sup>C serial interface. The interface supports video frame-by-frame LED string intensity control for up to 16 interconnected devices, allowing active area dimming when used for video displays. The advanced PWM engine synchronizes with the video signal, and offers phase shifted string drive, virtually eliminating waterfall noise and motion blur.

The MSL2100 adaptively controls up to three DC-DC converters, which power the LED strings, using patented Atmel's Driver Adaptive SourcePower™ technology. These Efficiency Optimizers minimize power use while maintaining LED current accuracy, and allow up to 16 interconnected devices to automatically negotiate the optimum power supply voltages.

A unique combination of peak current control and pulse width dimming management offers simple full-screen brightness control, versatile area dimming, and a consistent white point. LED string current is set for each string using a current sense (FET source) resistor. LED current is also digitally controlled for all eight LED strings. Global string drive pulse width is adjusted with a 6-bit global intensity register, and individual string pulse width is modulated with 8-bit control. Additionally, the MSL2100 optionally throttles back the PWM on time of all strings when the temperature of the LEDs exceeds a programmable threshold.

The MSL2100 monitors for string open circuit, LED short circuit, loss-of-sync and over temperature faults, and provides a hardware fault output to notify the MCU. Detailed fault status and control are available through the serial interface. Additionally, the MSL2100 includes an on-chip EEPROM that allows the power-up default register settings to be customized via the serial interface.

The MSL2100 is offered in a 6 x 6 x 0.85mm, 48-pin QFN package, and operates over a -40°C to +85°C temperature range.

## Applications

- Edge-lit LED Backlit TVs
- High-contrast Monitors
- Medical and Industrial Displays
- High-power LED Arrays
- Multi-string LED Lighting
- Solid-State Lighting (SSL)

## Ordering Information

| PART      | DESCRIPTION     | PACKAGE                |
|-----------|-----------------|------------------------|
| MSL2100BR | 8-Ch LED driver | 48 pin, 6x6x0.85mm QFN |

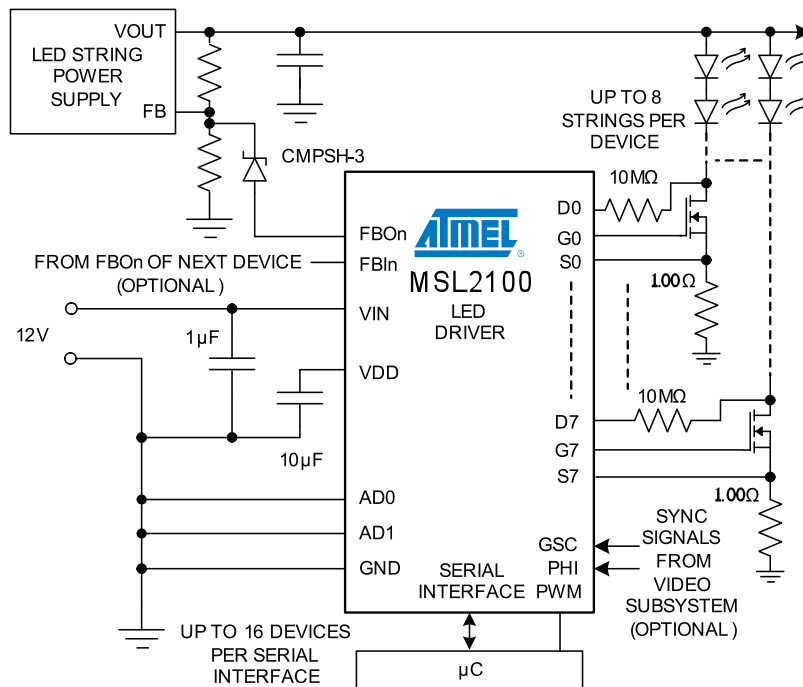
# Atmel LED Driver-MSL2100

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## Key Features

- 8-bit PWM String Dimming
- Fast, 1MHz I<sup>2</sup>C/SMBus Interface Supports up to 16 Devices per Bus
- 4-Bit Adaptive Power Correction Maximizes Efficiency of up to Three Power Supplies
- External MOSFETs allow >0.5A LED String Current
- Drives up to Eight Parallel High Power LED Strings
- Multiple MSL2100s Share String Supplies and Automatically Negotiate Optimum Voltages
- Supports Adaptive, Real-time 2-D Area Dimming for Highest Dynamic Range LCD TVs and Monitors
- Programmable String Phase Virtually Eliminates Motion Blur and Improves Efficiency
- Global LED Intensity Control via Serial Interface
- Supports Direct PWM Control of all LED Strings with a Single PWM Input Signal
- $\pm 1\%$  Current Accuracy and Current Balance
- Video Frame (VSYNC) and Line (HSYNC) Sync Inputs
- Sync Loss Detectors Optionally Disable LED Strings
- Internal EEPROM Allows Custom Power-up Default Settings
- String Open Circuit and LED Short Circuit Fault Detection
- <1 $\mu$ A LED String off Leakage Current
- External Resistors Set Individual String Peak Current
- Programmable LED Over-temperature Compensation
- Automatic Die Over-temperature Protection
- I<sup>2</sup>C/SMBus Broadcast Mode Simplifies Configuration
- -40°C To +85°C Operating Temperature Range
- Lead-free, Halogen-free, RoHS-compliant Package

## Application Circuit





## Quick Start Guide

The MSL2100 controls eight strings of series-connected LEDs at up to 1A per string, and up to sixteen devices may share the serial interface. The MSL2100 FET gate drive output is optimized for FETs requiring no more than 10nC of charge. The MSL2100 PWM engine generates the PWM signal that drives the strings or, optionally, accepts an external PWM signal.

### How Many LEDs and Drivers?

The MSL2100 drives eight strings of series-connected LEDs using external N-channel MOSFETs and current sense resistors. The LED drive capability (maximum number of LEDs per string) is limited only by the MOSFETs and the LED string power supplies, not by the MSL2100. Up to 16 MSL2100s may share an I<sup>2</sup>C/SMBus serial interface, with both individual and broadcast (all MSL2100s on a bus) addressing. The high LED drive power of the MSL2100 makes it suitable for large LCD TV and monitor backlights, as well as for LED signage and general lighting.

### LEDs, String Power Supplies, and the Efficiency Optimizer

The MSL2100 features three Efficiency Optimizer outputs that dynamically adjust the LED string power supplies to the minimum voltage necessary to drive the LED strings, minimizing power use while assuring accurate LED current flow. The Efficiency Optimizers feature an input that allows up to 16 devices to be connected in a chain configuration. When implemented, the chains automatically negotiate, control and optimize the string power supplies for all LED strings driven by each chain.

The power supplies can use any topology that employs external feedback resistors with a maximum feedback voltage of 1.5V, and are typically DC-DC boost converters. The Efficiency Optimizers rely on close matching of the LEDs connected to a string supply; the better the matching, the better the overall efficiency.

### Differences between Atmel LED Driver-MSL2100 and MSL3082

The MSL2100 includes three independent Efficiency Optimizer circuits to control three separate string supplies (for RGB LEDs for example). The MSL3082 includes a single Efficiency Optimizer, is more suited for single-color LEDs, and is ideal for driving white backlight LEDs in an LCD monitor or TV application.

### Timing, PWM, Intensity Controls, and Synchronization

The PWM LED drive signals synchronize to video frame timing via the PHI input, and to pixel timing via the GSC input. Suitability for LED backlight architectures is shown in Table 1 and Table 2. Area LED dimming for direct backlighting is supported for contrast and color gamut improvement. With area dimming, motion blur is reduced by setting each LED string's PWM phasing to synchronize string off times with the LCD update timing. Also, the individual PWM intensity registers for eight LED strings are updated with only 92 I<sup>2</sup>C/SMBus clocks. Sixteen drivers (128 LED strings) update in 1.47ms with a 1MHz bus speed, offering area dimming support for frame rates up to 640Hz.

# Atmel LED Driver-MSL2100

8-string, High-power, White or RGB LED Drivers for TVs, Monitors, or Intelligent Solid-state Lighting

**Table 1. Atmel LED Driver-MSL2100 LED Common Backlight Drive Architectures**

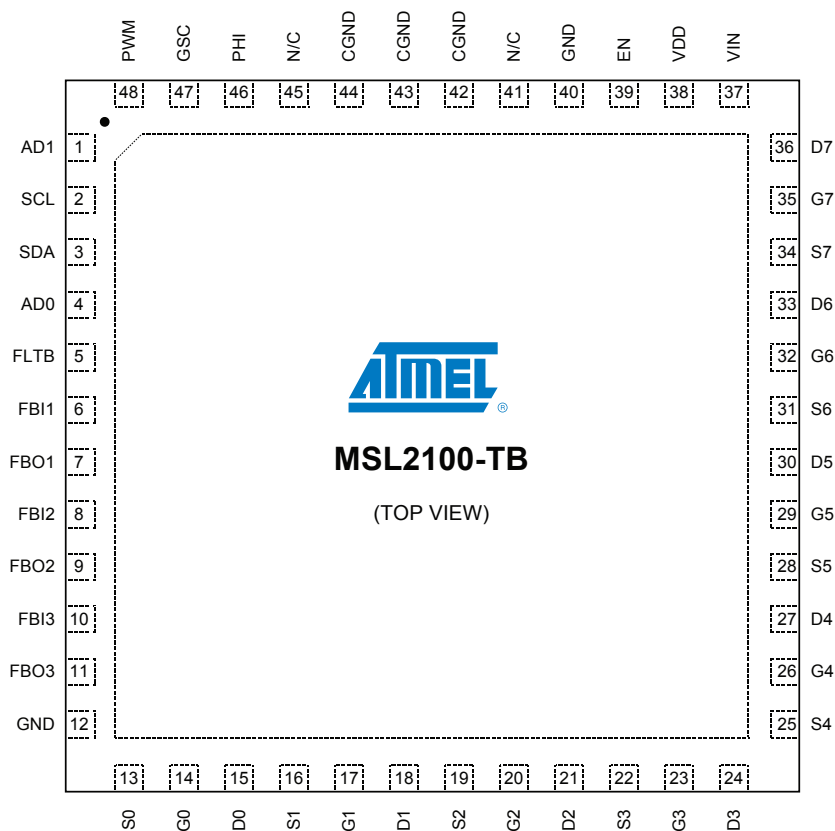
| BACKLIGHT TYPE                  | STRING SUPPLY OPTIONS                               | MOTION BLUR REMOVAL     | LED ZONE MANAGEMENT                   |
|---------------------------------|-----------------------------------------------------|-------------------------|---------------------------------------|
| White LED - bottom edge-lit     | One or more MSL2100 per Efficiency Optimized supply | No                      | No                                    |
| White LED - top/bottom edge-lit |                                                     | No                      | No                                    |
| White LED - four sides edge-lit |                                                     | No                      | No                                    |
| White LED - direct back-lit     |                                                     | Yes - LED strip phasing | Higher contrast ratio (area dimming)  |
| RGB LED - direct back-lit       |                                                     | Yes - LED strip phasing | Higher contrast ratio and color gamut |

**Table 2. Atmel LED Driver-MSL2100 Timing and LED Intensity Control Capability**

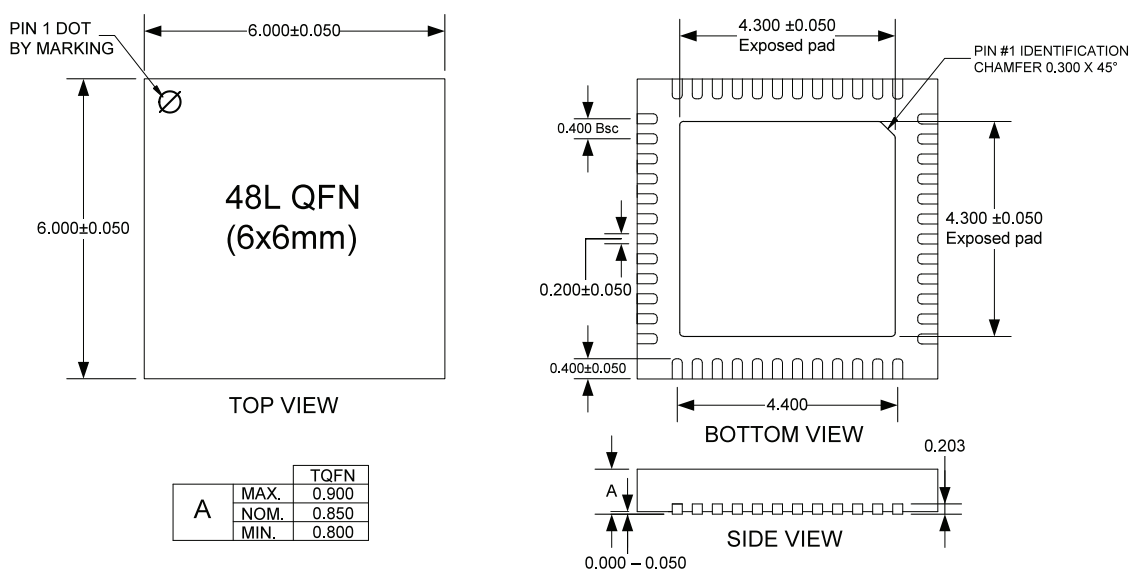
| LED INENSITY CONTROL                 | RESOLUTION                                                                             |
|--------------------------------------|----------------------------------------------------------------------------------------|
| Individual LED string current        | External resistors set maximum current for each LED string, up to at least 500mA       |
| Individual LED string current        | 6-bit ISTR registers reduce string current from maximum set by global resistor         |
| Global LED string pulse width        | 6-bit GINT register or PWM input (accepts 20Hz To 50kHz, 0% to 100% duty cycle)        |
| Individual LED string pulse width    | 8-bit PWM registers set individual string pulse width                                  |
| Global temperature derating          | 6-bit temperature pulse width derating individually applied to each string             |
| Total LED string pulse width control | 10-bit LED string pulse width computed from global and individual pulse width settings |



## Package Pin-out - Atmel LED Driver-MSL2100-TB



**Figure 1. 48-pin, 6mm x 6mm x 0.85mm QFN (0.4mm pin pitch) with Exposed Pad**



**Figure 2. 48-pin TQFN Package Dimensions**

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## Pin Descriptions

| PIN                            | NAME    | DESCRIPTION                                                                                                                                                                                                                                                                  |
|--------------------------------|---------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1                              | AD1     | <b>I<sup>2</sup>C slave ID selection inputs</b><br>AD1 and AD0 select the device I <sup>2</sup> C slave address.                                                                                                                                                             |
| 2                              | SCL     | <b>I<sup>2</sup>C serial clock input</b><br>SCL is the I <sup>2</sup> C serial interface clock input.                                                                                                                                                                        |
| 3                              | SDA     | <b>I<sup>2</sup>C serial data I/O</b><br>SDA is the I <sup>2</sup> C serial interface data I/O.                                                                                                                                                                              |
| 4                              | AD0     | <b>I<sup>2</sup>C slave ID selection inputs</b><br>AD0 and AD1 select the device I <sup>2</sup> C slave address.                                                                                                                                                             |
| 5                              | FLTB    | <b>Fault output (open drain, active low)</b><br>FLTB sinks current to GND when the MSL2100 detects a fault.<br>FLTB remains low until the fault registers have been read or EN is toggled low.                                                                               |
| 6                              | FBI1    | <b>Efficiency Optimizer input</b><br>Connect FBI1 to FBO1 of the next device when chaining the Efficiency Optimizers.<br>If unused, connect FBI1 to GND.                                                                                                                     |
| 7                              | FBO1    | <b>Efficiency Optimizer output</b><br>Connect FBO1 through a Schottky diode to the string power supply's feedback node (Figure 4) or to FBI1 of the previous device (Figure 5).<br>If unused, leave FBO1 unconnected.                                                        |
| 8                              | FBI2    | <b>Efficiency Optimizer input</b><br>Connect FBI2 to FBO2 of the next device when chaining the efficiency optimizers.<br>If unused, connect FBI2 to GND.                                                                                                                     |
| 9                              | FBO2    | <b>Efficiency Optimizer output</b><br>Connect FBO2 through a Schottky diode to the string power supply's feedback node (Figure 4) or to FBI2 of the previous device (Figure 5).<br>If unused, leave FBO2 unconnected.                                                        |
| 10                             | FBI3    | <b>Efficiency Optimizer input</b><br>Connect FBI3 to FBO3 of the next device when chaining the efficiency optimizers.<br>If unused connect FBI3 to GND.                                                                                                                      |
| 11                             | FBO3    | <b>Efficiency Optimizer output</b><br>Connect FBO3 through a Schottky diode to the string power supply's feedback node (Figure 4) or to FBI3 of the previous device (Figure 5).<br>If unused, leave FBO3 unconnected.                                                        |
| 12, 40                         | GND     | <b>Power ground</b><br>Connect GND to system ground, to CGND, and to EP with short, wide traces.                                                                                                                                                                             |
| 13, 16, 19, 22, 25, 28, 31, 34 | S0 - S7 | <b>String 0 thru 7 source sense inputs</b><br>Connect S <sub>n</sub> to the source of external MOSFET <sub>n</sub> and to the current sense resistor for LED string <sub>n</sub> .<br>The full-scale LED current is reached when 500mV is across the current sense resistor. |
| 14, 17, 20, 23, 26, 29, 32, 35 | G0 - G7 | <b>String 0 thru 7 external MOSFET gate drive outputs</b><br>Connect G <sub>n</sub> to the gate of external MOSFET <sub>n</sub> .                                                                                                                                            |
| 15, 18, 21, 24, 27, 30, 33, 36 | D0 - D7 | <b>String 0 thru 7 external MOSFET drain sense inputs</b><br>Connect D <sub>n</sub> to the drain of external MOSFET <sub>n</sub> through a 10MΩ resistor.                                                                                                                    |
| 37                             | VIN     | <b>Supply voltage input</b><br>Connect a 12V ±10% supply to VIN.<br>Bypass VIN to GND with a 1μF ceramic capacitor placed close to VIN.                                                                                                                                      |
| 38                             | VDD     | <b>Internal 2.5V regulator capacitor connection</b><br>Bypass VDD to GND with a 10μF ceramic capacitor placed close to the device.                                                                                                                                           |



| PIN         | NAME | DESCRIPTION                                                                                                                                                                       |
|-------------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 39          | EN   | <b>Enable input (active high)</b><br>Drive EN high to turn on the MSL2100, and drive it low to turn it off.<br>For automatic startup, connect EN to VIN through a 100kΩ resistor. |
| 41, 45      | N/C  | <b>No internal connection. Recommended to leave open.</b>                                                                                                                         |
| 42, 43, 44  | CGND | <b>Connect to ground</b><br>Connect CGND to system ground, to GND, and to EP using short, wide traces.                                                                            |
| 46          | PHI  | <b>Phase synchronization input</b><br>Drive PHI with an external signal from 40Hz to 10kHz to synchronize the PWM dimming to the signal at PHI.<br>Connect PHI to GND if unused.  |
| 47          | GSC  | <b>Gate shift clock input</b><br>Drive GSC with the gate shift clock of the video signal, up to 5MHz. GSC sets the resolution of PWM dimming.<br>Connect GSC to GND if unused.    |
| 48          | PWM  | <b>PWM input</b><br>Drive PWM with a pulse-width-modulated signal with a duty cycle of 0% to 100% and frequency of 20Hz to 50kHz to control the brightness of all LED strings.    |
| Exposed pad | EP   | <b>Power ground</b><br>Connect EP to system ground, GND, and CGND using short, wide traces.<br>EP offers thermal relief to the die.                                               |

## Absolute Maximum Ratings

### Voltage (With Respect to GND)

VIN, EN, D0-D7, G0-G7 ..... -0.3V to +16V  
 SDA, SCL, AD0, AD1, FLTB.....-0.3V to +5.5V  
 PHI, GSC, PWM, S0-S7, FBI1, FBI2, FBI3, FBO1, FBO2, FBO3 ..... -0.3V to ( $V_{DD} + 0.3V$ )  
 VDD ..... -0.3V to +2.75V

### Current (Into Pin)

VIN ..... 50mA  
 GND.....-500mA  
 All other pins.....20mA

### Continuous Power Dissipation (See Note 8, Note 9)

48-pin, 6mm x 6mm x 0.85mm QFN (derate 45.5mW/°C above 70°C) ..... 2500mW

**Ambient Operating Temperature Range**  $T_A = T_{MIN}$  to  $T_{MAX}$  ..... -40°C to +85°C

**Junction Temperature** ..... +125°C

**Storage Temperature Range** ..... -65°C to +125°C

**Lead Soldering Temperature, 10s** ..... +300°C

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## Electrical Characteristics

(Circuit of Figure 3, VIN = 12V, T<sub>A</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>, unless otherwise noted. Typical values are at VIN = 12V, T<sub>A</sub> = +25°C)

| PARAMETER                                                   | CONDITIONS AND NOTES                                                | MIN  | TYP  | MAX  | UNIT            |
|-------------------------------------------------------------|---------------------------------------------------------------------|------|------|------|-----------------|
| <b>DC ELECTRICAL CHARACTERISTICS</b>                        |                                                                     |      |      |      |                 |
| VIN operating supply voltage                                |                                                                     | 10.8 | 12.0 | 13.2 | V               |
| VIN operating supply current                                | All drivers on at 100% duty, I <sup>2</sup> C serial interface idle |      | 25.0 | 32.5 | mA              |
| VIN shutdown supply current                                 | EN = 0, all digital inputs tied to VDD or GND                       |      | 10   | 20   | μA              |
| VDD regulation voltage                                      |                                                                     | 2.3  | 2.5  | 2.6  | V               |
| Input high voltage<br>SDA, SCL, AD0, AD1                    |                                                                     | 2.31 |      |      | V               |
| Input low voltage SDA, SCL, AD0, AD1                        |                                                                     |      |      | 0.9  | V               |
| Input high voltage PHI, GSC, PWM                            |                                                                     | 1.8  |      |      | V               |
| Input low voltage PHI, GSC, PWM                             |                                                                     |      |      | 0.7  | V               |
| Input high voltage EN                                       |                                                                     | 0.9  | 1.36 |      | V               |
| Input low voltage EN                                        |                                                                     |      |      | 0.7  | V               |
| Input hysteresis EN                                         |                                                                     |      | 50   |      | mV              |
| Input quiescent current EN                                  |                                                                     |      | 1    | 20   | μA              |
| SDA, FLTB output low voltage                                | Sinking 6mA                                                         |      |      | 0.4  | V               |
| S0 thru S7 regulation resolution                            |                                                                     |      | 1    |      | % of Full Scale |
| Open circuit detect voltage                                 |                                                                     | 7.3  | 8.3  | 9.0  | V               |
| Short circuit detect voltage                                |                                                                     | 6.5  | 7.8  | 9.0  | V               |
| D0 thru D7 leakage current                                  | Voltage under 9V                                                    |      | 0.1  |      | μA              |
|                                                             | Voltage between 9V to 16V                                           |      |      | 15   |                 |
| G0 thru G7 maximum gate drive voltage                       |                                                                     |      | 10   |      | V               |
| G0 thru G7 gate drive current                               |                                                                     | -20  |      | 20   | mA              |
| Current sense regulation voltage                            | ISTRn = 0x3F                                                        | 488  | 500  | 508  | mV              |
|                                                             | ISTRn = 0x1F                                                        | 235  | 250  | 255  | mV              |
| G0 thru G7 output current slew rate                         | Current rising (Note 7, Note 8)                                     |      | 10   |      | mA/μs           |
|                                                             | Current falling (Note 7, Note 8)                                    |      | 10   |      |                 |
| Thermal cut-off temperature                                 |                                                                     |      | 135  |      | °C              |
| FBI <sub>n</sub> to FBO <sub>n</sub> current transfer error | Up to FBO <sub>n</sub> maximum output current                       |      | ±2   |      | %               |
| FBO <sub>n</sub> current step size                          |                                                                     |      | 3    |      | μA              |
| FBO <sub>n</sub> feedback output current maximum            | V <sub>FBO_</sub> = 0 to 1.8V                                       | 35   | 45   | 55   | μA              |



| PARAMETER                     | CONDITIONS AND NOTES                                        | MIN | TYP | MAX    | UNIT       |
|-------------------------------|-------------------------------------------------------------|-----|-----|--------|------------|
| AC ELECTRICAL CHARACTERISTICS |                                                             |     |     |        |            |
| OSC initial accuracy          | $f_{OSC}$ OSCCTRL = 0x04 ( $f_{OSC}$ = 20MHz); $T_A$ = 25°C | 18  | 20  | 22     | MHz        |
| PHI frequency                 | $f_{PHI}$ (Note 7)                                          | 40  |     | 10,000 | Hz         |
| GSC frequency                 | $f_{GSC}$ (Note 7)                                          |     |     | 5      | MHz        |
| PWM frequency                 | $f_{PWM}$ PWMDIRECT = PWMEN = 1                             | 20  |     | 50,000 | Hz         |
| PWM duty cycle                | PWMDIRECT = PWMEN = 1                                       | 0   |     | 100    | %          |
| PHI DLL lock cycles           |                                                             |     | 4   |        | PHI Cycles |

| PARAMETER                                  | CONDITIONS AND NOTES                                            | MIN  | TYP | MAX   | UNIT |
|--------------------------------------------|-----------------------------------------------------------------|------|-----|-------|------|
| I <sup>2</sup> C SWITCHING CHARACTERISTICS |                                                                 |      |     |       |      |
| SCL clock frequency                        | $1/t_{SCL}$ Bus timeout disabled (Note 1)                       | 0    |     | 1,000 | kHz  |
| Bus timeout period                         | $t_{TIMEOUT}$ OSCCTRL = 0x04 ( $f_{OSC}$ = 20MHz); $T_A$ = 25°C | 27   | 30  | 33    | ms   |
| 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 set-up time       | $t_{SU:STA}$                                                    | 0.26 |     |       | μs   |
| STOP condition set-up time                 | $t_{SU:STOP}$                                                   | 0.26 |     |       | μs   |
| SDA data hold time                         | $t_{HD:DAT}$                                                    | 15   |     |       | ns   |
| SDA data valid acknowledge time            | $t_{VD:ACK}$ (Note 2)                                           | 0.05 |     | 0.55  | μs   |
| SDA data valid time                        | $t_{VD:DAT}$ (Note 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                         | $t_F$ (Note 4, Note 5)                                          |      |     | 120   | ns   |
| SDA, SCL rise time                         | $t_R$                                                           |      |     | 120   | ns   |
| SDA, SCL input suppression filter period   | $t_{SP}$ (Note 6)                                               |      | 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  $t_{TIMEOUT}$ . Disable bus timeout feature for DC operation

Note 2.  $t_{VD:ACK}$  = 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 are 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. The MSL2100 includes input filters on SDA, SCL, AD0, and AD1 inputs that suppress noise less than 50ns

Note 7. Parameter is guaranteed by design, and is not production tested

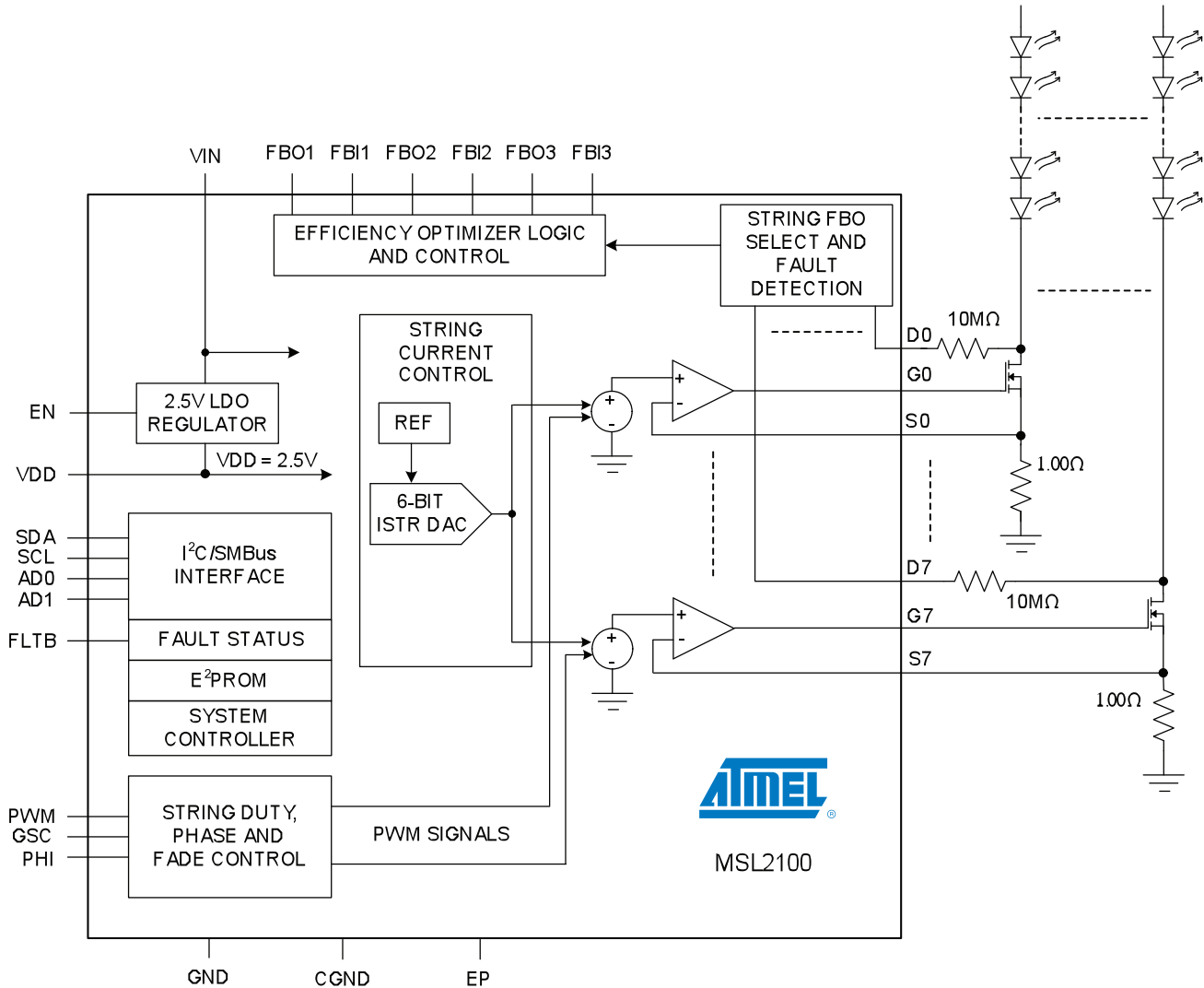
Note 8. Subject to thermal dissipation characteristics of the device

Note 9. When mounted according to JEDEC JEP149 and JESD51-12 for a one-layer PCB,  $\theta_{JA}$  = 22°C/W and  $\theta_{JC}$  = 1.3°C/W

# Atmel LED Driver-MSL2100

8-string, High-power, White or RGB LED Drivers for TVs, Monitors, or Intelligent Solid-state Lighting

## Block Diagram



## Atmel LED Driver-MSL2100 Typical Application Circuit

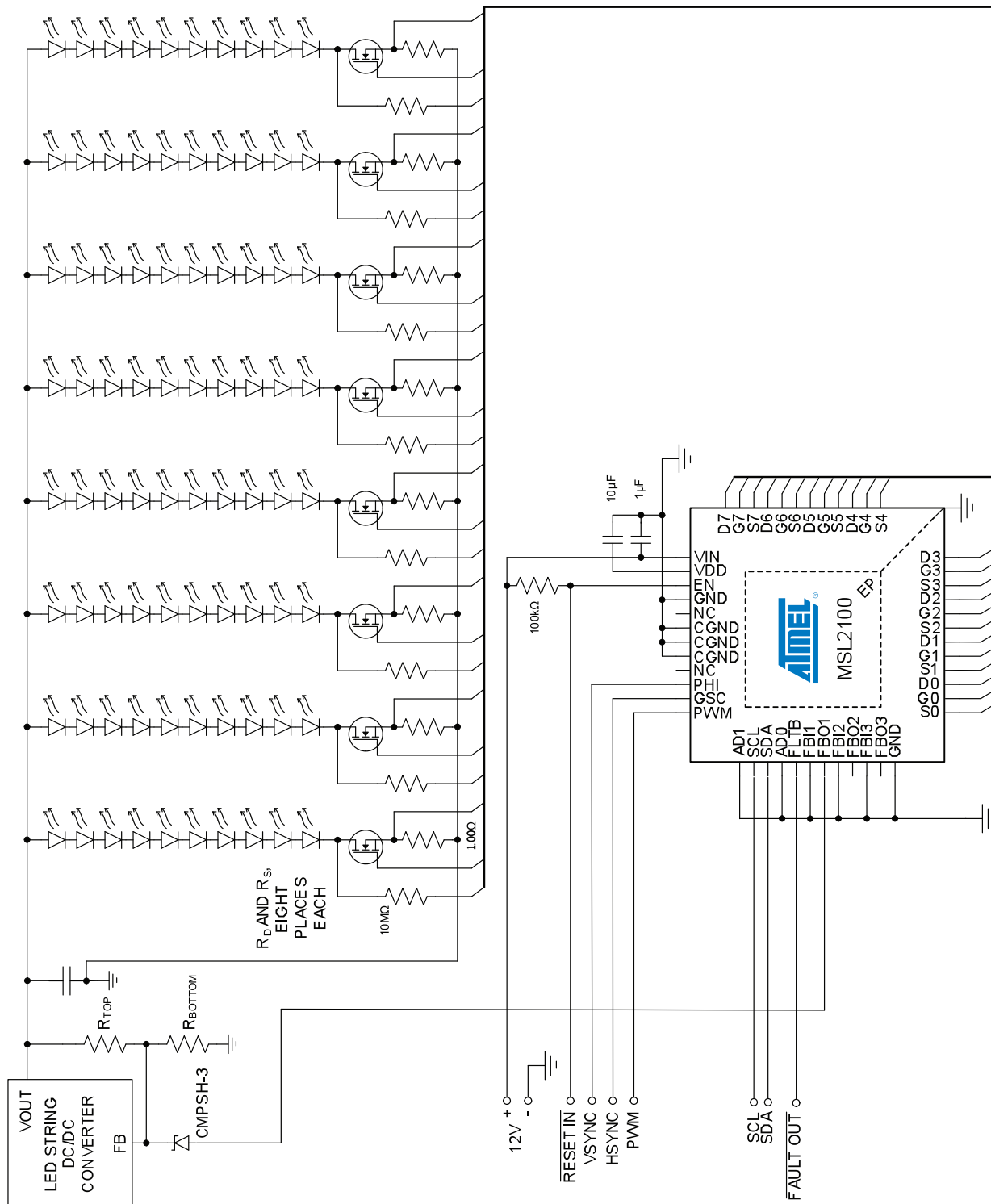


Figure 3. Typical Application Circuit

# Atmel LED Driver-MSL2100

8-string, High-power, White or RGB LED Drivers for TVs, Monitors, or Intelligent Solid-state Lighting

## Detailed Description

The MSL2100 is a highly integrated, flexible, multi-string LED driver that uses external MOSFETs to allow high LED string currents and includes power supply control for three supplies to maximize efficiency. The driver optionally connects to a video subsystem to offer easy synchronization for use in LCD TV backlight applications. Up to sixteen devices may be connected together to drive a large number of LED strings in a system. The drivers provide multiple methods of controlling LED brightness through both peak current control and pulse width control of the string drive signals. Peak current control offers excellent color consistency, while pulse width control allows brightness management. An on-chip EEPROM holds all the default control register values. At power-up, the data in the EEPROM are automatically copied directly to the control registers, setting up the device for operation. The factory programmed EEPROM values are changeable through the serial interface if a different power-up condition is desired.

The device interfaces to an MCU via the I<sup>2</sup>C/SMBus interface. The robust 1MHz I<sup>2</sup>C/SMBus interface supports up to sixteen devices on the bus, and is fast enough to support area dimming for 16 interconnected devices. While typically the LED drive PWM signal is internally generated by the PWM engine, the device also accepts an external direct PWM drive signal applied to the PWM input to set the duty cycle and the frequency of the LED drive signals. When using the PWM engine, the MSL2100 allows phase spreading of the LED drive signals, which helps reduce the transient load on the LED power supplies. Phase spreading is not supported for direct PWM drive.

The PWM frequency of the drivers is easily synchronized to an external video signal applied to PHI. Typically, the VSYNC signal from the video system is used as the PHI input. A frame-rate multiplier (1x to 16x) processes this signal for use by the PWM engine. The on time of each string is individually programmed via the device registers, providing a peak resolution of 10 bits when using the on-chip PWM generator. The actual resolution

of the PWM frequency depends on the ratio of the GSC frequency (typically provided by a systems HSYNC signal) to the PHI frequency because the on time of a string is programmed as a function (8-bit count) of the number of GSC cycles. This count can be further scaled by a 6-bit global intensity register, when enabled. The GSC clock is also used to precisely set each string's phase delay to be synchronized with its physical position relative to the video frame. Additionally, the MSL2100 features programmable temperature compensation, which throttles back the PWM on time of all strings when the temperature of the LEDs exceeds a programmable threshold.

The Efficiency Optimizers control a wide range of different external DC-DC and AC-DC converter architectures. Multiple drivers in a system communicate in real time among themselves to select an optimized operating voltage for the LEDs. This allows design of the power supplies for the worst case forward voltage ( $V_f$ ) of the LEDs without concern about excessive power dissipation issues. During the start-up sequence, the MSL2100 automatically reduces the power supply voltage to the minimum required to keep the LEDs in current regulation. The devices are configured to periodically perform this optimization to compensate for changes in LED forward voltage, and to assure continued optimum power savings.

## Internal Regulators and Enable Input

The MSL2100 includes an internal linear regulator powered from VIN that provides 2.5V, VDD, to power the internal circuitry. Bypass VDD to GND with a 10μF or greater capacitor.

The enable input, EN, turns the VDD regulator on and off. To turn on the MSL2100, force EN high with a 5V logic level, and force EN low to turn it off. When EN is low, the MSL2100 enters low-power mode, and the serial interface is ignored. Toggling EN low also clears all fault registers and releases FLTB. Faults re-establish if the conditions that generated them persist.



## Setting LED String Currents

The maximum string current,  $I_{LED}$ , for each string is set by a resistor,  $R_{Sn}$ , connected to ground from the source terminal of the external string drive MOSFET. The feedback threshold is 500mV. Determine the resistor value using:

$$R_{Sn} = \frac{0.5}{I_{LED}}, \quad \text{where } I_{LED} \text{ is in amperes and } R_{Sn} \text{ is in ohms.}$$

For example, a full-scale LED current of 500mA returns  $R_{Sn} = 1.00\Omega$ . The current for the LED strings is individually reduced from the full-scale resistor set value with 6-bit resolution using  $ISTR_n$ , the string current control registers 0x10 through 0x1F.

## Connecting an LED String Power Supply to an Efficiency Optimizer Output

The MSL2100 is designed to control up to three external LED string power supplies that use voltage dividers ( $R_{TOP}$  and  $R_{BOTTOM}$  in Figure 4) to set the output voltage, and whose regulation feedback voltage is not more than 1.5V. The Efficiency Optimizer improves power efficiency by injecting a current of between 0 and 45 $\mu$ A into the voltage dividers of the external power supplies, dynamically adjusting their outputs to the minimum voltage required by the LED strings. To select the resistors, first determine  $V_{OUT(MIN)}$  and  $V_{OUT(MAX)}$ , the minimum and maximum string supply voltage limits, using:

$$V_{OUT(MIN)} = (V_{f(MIN)} * [\#ofLEDs]) + 0.5,$$

and

$$V_{OUT(MAX)} = (V_{f(MAX)} * [\#ofLEDs]) + 0.5,$$

where  $V_{f(MIN)}$  and  $V_{f(MAX)}$  are the LED minimum and maximum forward voltage drops at the peak current set by  $R_{Sn}$  (page\_). For example, if the LED data are  $V_{f(MIN)} = 3.5V$  and  $V_{f(MAX)} = 3.8V$ , and ten LEDs are used in a string, then the total minimum and maximum voltage drops across a string are 35V and 38V, respectively. Adding an allowance of 0.5V for the string drive MOSFET headroom brings  $V_{OUT(MIN)}$  to 35.5V and  $V_{OUT(MAX)}$  to 38.5V. Then, determine  $R_{TOP}$  using:

$$R_{TOP} = \frac{V_{OUT(MAX)} - V_{OUT(MIN)}}{I_{FBOn(MAX)}},$$

where  $I_{FBOn(MAX)}$  is the 45 $\mu$ A maximum output current of the Efficiency Optimizer outputs, FBO1, FBO2, and FBO3. Finally, determine  $R_{BOTTOM}$  using:

$$R_{BOTTOM} = R_{TOP} * \frac{V_{FB}}{V_{OUT(MAX)} - V_{FB}},$$

where  $V_{FB}$  is the regulation feedback voltage of the power supply. Place a Schottky diode (CMPSH-3 or similar) between FBO<sub>n</sub> and the supply's feedback node to protect the MSL2100 against current flow into FBO<sub>n</sub>.

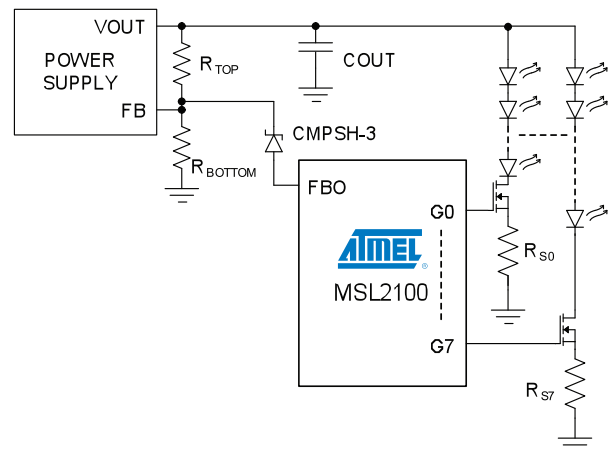


Figure 4. FBO<sub>n</sub> Connection to Power Supply Voltage Divider

# Atmel LED Driver-MSL2100

8-string, High-power, White or RGB LED Drivers for TVs, Monitors, or Intelligent Solid-state Lighting

## Using Multiple Atmel LED Driver-MSL2100s to Control a Single Power Supply

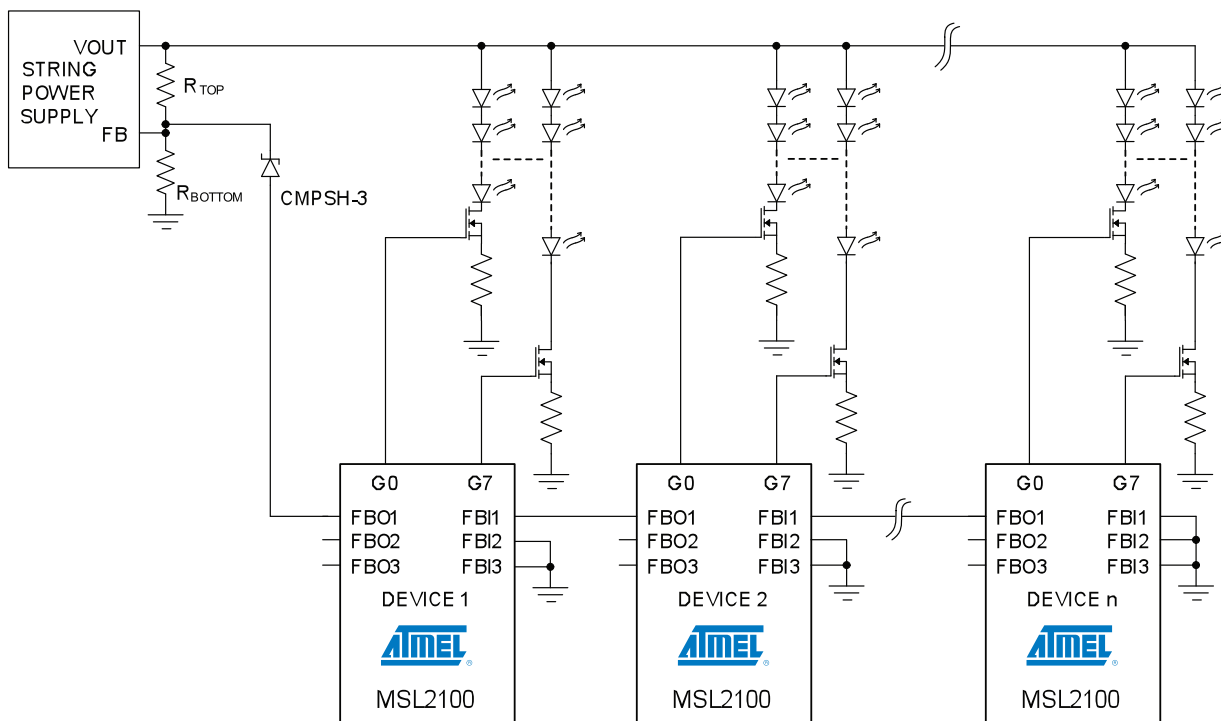
Cascade multiple MSL2100 devices into a chain configuration (Figure 5) with the FBIn of one device connected to the FBO<sub>n</sub> of the next. Connect the first FBO<sub>n</sub> to the power supply feedback resistor node through a CMPSH-3 or similar Schottky diode, and the unused FBIn input to ground as close to the MSL2100 as possible. The chained devices work together to ensure that the system operates at optimum efficiency. Note that the accuracy of the feedback chain has the potential to degrade through each link of the FBIn/FBO<sub>n</sub> chain by as much as 2%. Determine the worst case maximum FBO<sub>n</sub> current,  $I_{FBO_n(MAX/MIN)}$ , using:

$$I_{FBO_n(MAX/MIN)} = 45\mu A * (0.98)^{N-1},$$

where N is the number of MSL2100s connected in series. Use this result in the above  $R_{TOP}$  resistor equation for the term  $I_{FBO_n(MAX)}$  instead of using the 45μA figure shown here.

Take care in laying out the traces for the Efficiency Optimizer connections. Minimize the FBIn/FBO<sub>n</sub> trace lengths as much as possible. Do not route the signals close to traces with large variations in voltage or current because noise may couple into FBIn. If these traces must be routed near noisy signals, shield them from noise by using ground planes and/or guard traces.

**Figure 5. Cascade Multiple Atmel LED Driver-MSL2100s to Control a Common Power Supply**





## Register Map Summary

Control the MSL2100 using the registers in the range 0x00 through 0x57 (Table 3). Two additional registers, 0x90 and 0x91, allow access to, and programming of, the EEPROM. The power-up default values for all control registers are stored within the on-chip EEPROM, and any of these EEPROM values may be changed through the serial interface.

**Table 3. Atmel LED Driver-MSL2100 Register Map**

| REGISTER AND ADDRESS |      | FUNCTION                               | REGISTER DATA |          |              |             |              |                      |              |          |
|----------------------|------|----------------------------------------|---------------|----------|--------------|-------------|--------------|----------------------|--------------|----------|
|                      |      |                                        | D7            | D6       | D5           | D4          | D3           | D2                   | D1           | D0       |
| CONTROL              | 0x00 | LED string enables                     | STR7EN        | STR6EN   | STR5EN       | STR4EN      | STR3EN       | STR2EN               | STR1EN       | STR0EN   |
| 0X01                 |      |                                        | UNUSED        |          |              |             |              |                      |              |          |
| POWERCTRL            | 0x02 | Power control                          | SLEEP         | -        | STRSCEN      | STROCEN     | PWMDIRECT    | I <sup>2</sup> CTOEN | FBOEN        | PHADLYEN |
| OSCCTRL              | 0x03 | Oscillator frequency                   | -             | -        | -            | -           | -            | OSCFREQ[2:0]         |              |          |
| OTTEMP               | 0x04 | Over-temp threshold                    | OTTEMP[7:0]   |          |              |             |              |                      |              |          |
| SYSTEMP              | 0x05 | System temperature                     | SYSTEMP[7:0]  |          |              |             |              |                      |              |          |
| OTSLOPE              | 0x06 | Over-temp derating                     | OTSLOPE[7:0]  |          |              |             |              |                      |              |          |
| FLTSTATUS*           | 0x07 | Fault status, global                   | -             | STRSCDET | STROCDET     | -           | -            | -                    | FBOCAL       | FLTDET   |
| PWMCTRL              | 0x08 | PWM and phase control, configuration   | GSCDIVEN      | GINTEN   | PHIPOL       | TDERATE     | PHIMINEN     | GSCMAXEN             | OVRFLOEN     | PWMEN    |
| OCSTAT*              | 0x09 | String open circuit status             | OC7           | OC6      | OC5          | OC4         | OC3          | OC2                  | OC1          | OC0      |
| SCSTAT*              | 0X0A | LED short circuit status               | SC7           | SC6      | SC5          | SC4         | SC3          | SC2                  | SC1          | SC0      |
| GINT                 | 0x0B | Global intensity                       | -             | -        | GINT[6:0]    |             |              |                      |              |          |
| GSCDIV               | 0x0C | GSC divider                            | -             | -        | -            | -           | GSCDIV[3:0]  |                      |              |          |
| PHIMUL               | 0x0D | PHI multiplier                         | -             | -        | -            | PHIMUL[4:0] |              |                      |              |          |
| STR03FBO             | 0x0E | String FBO enables                     | STR3FBO[1:0]  |          | STR2FBO[1:0] |             | STR1FBO[1:0] |                      | STR0FBO[1:0] |          |
| STR47FBO             | 0x0F |                                        | STR7FBO[1:0]  |          | STR6FBO[1:0] |             | STR5FBO[1:0] |                      | STR4FBO[1:0] |          |
| ISTR0                | 0x10 | Individual string current throttle     | -             | -        | ISTR0[5:0]   |             |              |                      |              |          |
| to                   |      |                                        | -             | -        | to           |             |              |                      |              |          |
| ISTR7                | 0x1F |                                        | -             | -        | ISTR7[5:0]   |             |              |                      |              |          |
| PHDLY0               | 0x20 | Individual string phase delay settings | PHDLY0[7:0]   |          |              |             |              |                      |              |          |
| to                   |      |                                        | to            |          |              |             |              |                      |              |          |
| PHDLY7               | 0x2F |                                        | PHDLY7[7:0]   |          |              |             |              |                      |              |          |

# Atmel LED Driver-MSL2100

8-string, High-power, White or RGB LED Drivers for TVs,  
Monitors, or Intelligent Solid-state Lighting

| REGISTER AND ADDRESS                     |      | FUNCTION                                   | REGISTER DATA  |             |              |        |              |             |              |         |
|------------------------------------------|------|--------------------------------------------|----------------|-------------|--------------|--------|--------------|-------------|--------------|---------|
|                                          |      |                                            | D7             | D6          | D5           | D4     | D3           | D2          | D1           | D0      |
| PWM0                                     | 0x30 | Individual string pulse width settings     | PWM0[7:0]      |             |              |        |              |             |              |         |
| to                                       |      |                                            | to             |             |              |        |              |             |              |         |
| PWM7                                     | 0x3F |                                            | PWM7[7:0]      |             |              |        |              |             |              |         |
| GSCMAX                                   | 0x40 | Max oscillator cycles between GSC Pulses   | GSCMAX[7:0]    |             |              |        |              |             |              |         |
|                                          | 0x41 |                                            | GSCMAX[15:8]   |             |              |        |              |             |              |         |
| PHIMIN                                   | 0x42 | Min GSC pulses over PHI period             | PHIMIN[7:0]    |             |              |        |              |             |              |         |
|                                          | 0x43 |                                            | -              | -           | -            | -      | PHIMIN[15:8] |             |              |         |
| 0X44 THRU 0X46                           |      |                                            | UNUSED         |             |              |        |              |             |              |         |
| FAULTEN                                  | 0x47 | Individual string fault monitoring enables | FLTEN7         | FLTEN6      | FLTEN5       | FLTEN4 | FLTEN3       | FLTEN2      | FLTEN1       | FLTEN0  |
| 0x48 thru 0x4F                           |      |                                            | UNUSED         |             |              |        |              |             |              |         |
| FBOCTRL0                                 | 0x50 | Efficiency Optimizer configuration         | HDRMSTEP[1:0]  |             | FBCLDLY[1:0] |        | FBSDLY[1:0]  |             | FBCFDLY[1:0] |         |
| FBOCTRL1                                 | 0x51 |                                            | STRSCCDLY[1:0] |             | -            | -      | -            | -           | ACALEN       | ICHKDIS |
| 0X52 THRU 0X56                           |      |                                            | UNUSED         |             |              |        |              |             |              |         |
| FBO1DAC*                                 | 0x57 | Efficiency Optimizer DAC readback          | FBO1ACT        | -           | -            | -      | FBO1DAC[3:0] |             |              |         |
| FBO2DAC*                                 | 0x58 | Efficiency Optimizer DAC readback          | FBO2ACT        | -           | -            | -      | FBO2DAC[3:0] |             |              |         |
| FBO3DAC*                                 | 0x59 | Efficiency Optimizer DAC readback          | FBO3ACT        | -           | -            | -      | FBO3DAC[3:0] |             |              |         |
| DO NOT ACCESS ADDRESS RANGE 0X5A TO 0X8F |      |                                            |                |             |              |        |              |             |              |         |
| E2ADDR                                   | 0x90 | User EEPROM read/write access              | -              | E2ADDR[6:0] |              |        |              |             |              |         |
| E2CTRLSTA                                | 0x91 |                                            | E2BUSY         | BLDACT      | E2ERR        | -      | -            | RWCTRL[1:0] |              |         |

\* Read-only registers



## Register Power-up Defaults

Register power-up default values are shown in Table 4.

**Table 4. Atmel LED Driver-MSL2100 Register Power-up Defaults**

| REGISTER NAME<br>AND ADDRESS |                        | POWER-UP CONDITION<br>REGIASTERS INITIALIZED FROM EEPROM                                                                                                                                                                                                                                                                                                        | REGISTER DATA |    |    |    |    |    |    |    |     |
|------------------------------|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----|----|----|----|----|----|----|-----|
|                              |                        |                                                                                                                                                                                                                                                                                                                                                                 | D7            | D6 | D5 | D4 | D3 | D2 | D1 | D0 | HEX |
| 0x00                         | CONTROL                | All LED strings drive outputs are enabled                                                                                                                                                                                                                                                                                                                       | 1             | 1  | 1  | 1  | 1  | 1  | 1  | 1  | FF  |
| 0x02                         | POWERCTRL              | String phase delay enabled<br>Efficiency Optimizer feedback output enabled<br>I <sup>2</sup> C bus timeout enabled<br>Direct PWM disabled<br>String open circuit detection enabled<br>String short circuit detection enabled<br>Device awake                                                                                                                    | 0             | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 77  |
| 0x03                         | OSCCTRL                | Internal oscillator f <sub>OSC</sub> set to 20MHz                                                                                                                                                                                                                                                                                                               | 0             | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 04  |
| 0x04                         | OTTEMP                 | Over-temperature threshold is 90°C                                                                                                                                                                                                                                                                                                                              | 0             | 1  | 0  | 1  | 1  | 0  | 1  | 0  | 5A  |
| 0x05                         | SYSTEMP                | System temperature set to 30°C                                                                                                                                                                                                                                                                                                                                  | 0             | 0  | 0  | 1  | 1  | 1  | 1  | 0  | 1E  |
| 0x06                         | OTSLOPE                | Over-temperature slope set to 50°C                                                                                                                                                                                                                                                                                                                              | 0             | 0  | 1  | 1  | 0  | 0  | 1  | 0  | 32  |
| 0x08                         | PWMCTRL                | PWM operation enabled<br>String on times truncated at end of frame<br>GSC low frequency fault detection disabled<br>PHI high frequency fault detection disabled<br>Over-temperature derating of string on times enabled<br>PWM frame synchronized to rising edge at PHI input<br>GINT global intensity control enabled<br>GSC input frequency division disabled | 0             | 1  | 1  | 1  | 0  | 0  | 0  | 1  | 71  |
| 0x0B                         | GINT                   | Global intensity PWM duty cycle GINT = 15/64 = 23.4%                                                                                                                                                                                                                                                                                                            | 0             | 0  | 0  | 0  | 1  | 1  | 1  | 1  | 0F  |
| 0x0C                         | GSCDIV                 | GSC input frequency is divided by 2 <sup>0</sup>                                                                                                                                                                                                                                                                                                                | 0             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 00  |
| 0x0D                         | PHIMUL                 | PHI input frequency is multiplied by 1                                                                                                                                                                                                                                                                                                                          | 0             | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 01  |
| 0x0E                         | STR03FBO               | All strings are monitored by the Efficiency Optimizer and are assigned to the FBO outputs as follows:<br>FBO1: Strings 0 and 4<br>FBO2: Strings 1, 2, 5 and 6<br>FBO3: Strings 3 and 7                                                                                                                                                                          | 1             | 1  | 1  | 0  | 1  | 0  | 0  | 1  | E9  |
| 0x0F                         | STR47FBO               |                                                                                                                                                                                                                                                                                                                                                                 | 1             | 1  | 1  | 0  | 1  | 0  | 0  | 1  | E9  |
| 0x10<br>0x17                 | ISTR0<br>thru<br>ISTR7 | Individual peak string current $= \frac{0.5}{R_{Sn}} * \frac{32}{63}$                                                                                                                                                                                                                                                                                           | 0             | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 20  |

# Atmel LED Driver-MSL2100

8-string, High-power, White or RGB LED Drivers for TVs,  
Monitors, or Intelligent Solid-state Lighting

| REGISTER NAME<br>AND ADDRESS |                          | POWER-UP CONDITION<br>REGISTERS INITIALIZED FROM EEPROM                                                                                                                                                            | REGISTER DATA |    |    |    |    |    |    |    |     |
|------------------------------|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----|----|----|----|----|----|----|-----|
|                              |                          |                                                                                                                                                                                                                    | D7            | D6 | D5 | D4 | D3 | D2 | D1 | D0 | HEX |
| 0x20<br>0x27                 | PHDLY0<br>thru<br>PHDLY7 | All string phase delays set to zero processed GSC cycles                                                                                                                                                           | 0             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 00  |
| 0x30<br>0x37                 | PWM0<br>thru<br>PWM7     | All strings PWM settings equal 48 processed GSC cycles                                                                                                                                                             | 0             | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 30  |
| 0x40                         | GSCMAX                   | Maximum GSC pulse count is 0                                                                                                                                                                                       | 0             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 00  |
| 0x41                         |                          |                                                                                                                                                                                                                    | 0             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 00  |
| 0x42                         | PHIMIN                   | Minimum PHI pulse count is 0                                                                                                                                                                                       | 0             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 00  |
| 0x43                         |                          |                                                                                                                                                                                                                    | 0             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 00  |
| 0x47                         | FAULTEN                  | Fault detection is enabled for all strings                                                                                                                                                                         | 1             | 1  | 1  | 1  | 1  | 1  | 1  | 1  | FF  |
| 0x50                         | FBOCTRL0                 | Current source error confirmation delay is 4μs<br>FBO on power supply settling time allowance is 8ms<br>Efficiency Optimizer auto recalibration delay is 1s<br>Efficiency Optimizer gives three steps for headroom | 0             | 0  | 0  | 0  | 1  | 1  | 0  | 0  | 0C  |
| 0x51                         | FBOCTRL1                 | Current source error detection enabled<br>Auto recalibration disabled<br>String short circuit confirmation delay is 4μs                                                                                            | 0             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 00  |
| 0x90                         | E2ADDR                   | User EEPROM 7-bit address = 0x00                                                                                                                                                                                   | 0             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 00  |
| 0x91                         | E2CTRLSTA                | User EEPROM read/write disabled                                                                                                                                                                                    | 0             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 00  |

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