Automotive LED Lighting

Oct 2014

- TPS92661-Q1 :

High-Brightness LED Matrix Manager for Automotive Headlight Systems

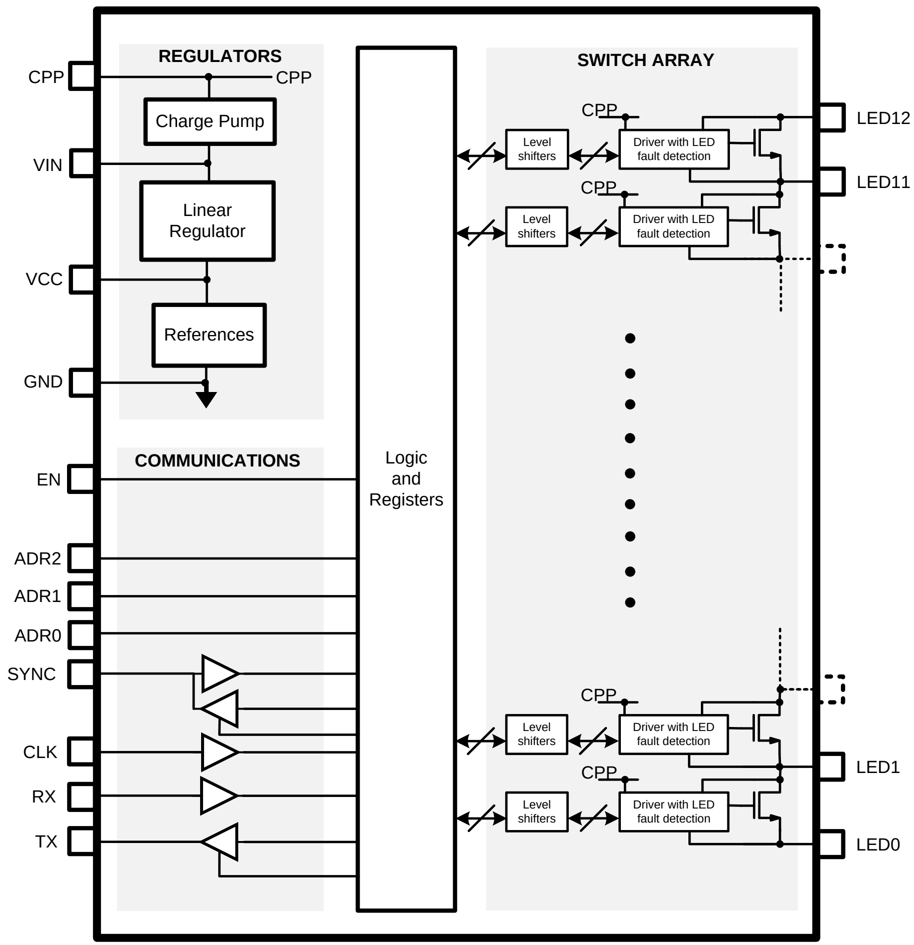
- TPS92630/1-Q1 :

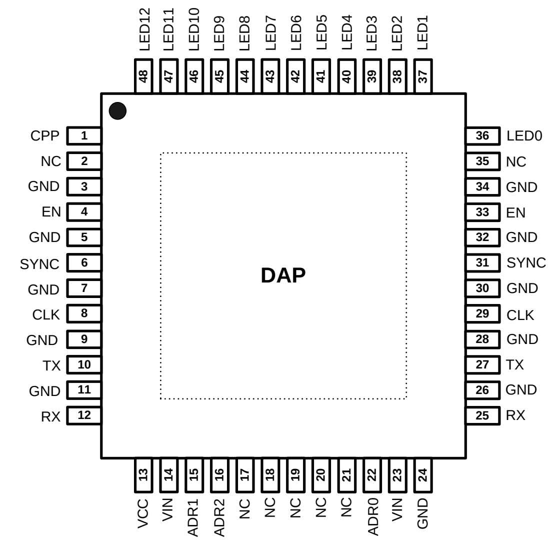
Three-Channel Linear LED Driver With Analog and PWM Dimming

- TPS92602 –Q1:

2 channel High Side Current Sense Switching LED Driver

TPS92661 LED Matrix Manager (LMM)





Features

- 12 Integrated bypass switches
- Integrated 10-bit PWM Generator
- UART Interface
- Integrated Charge-Pump
- Integrated fault detection reporting
- Feed-through architecture
- Q100 Grade 1 Qualified
- 48-pin TQFP Package

Applications

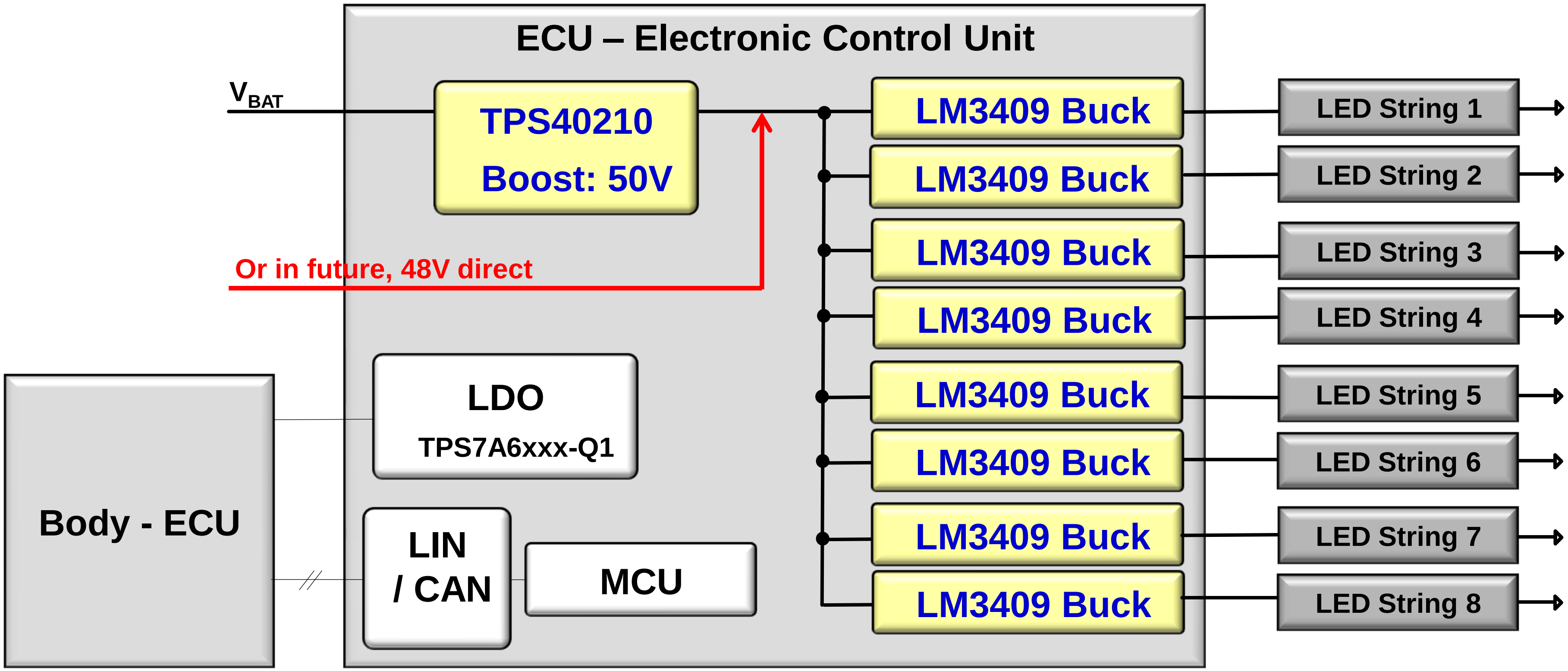
- Automotive Exterior LED Lighting

Benefits

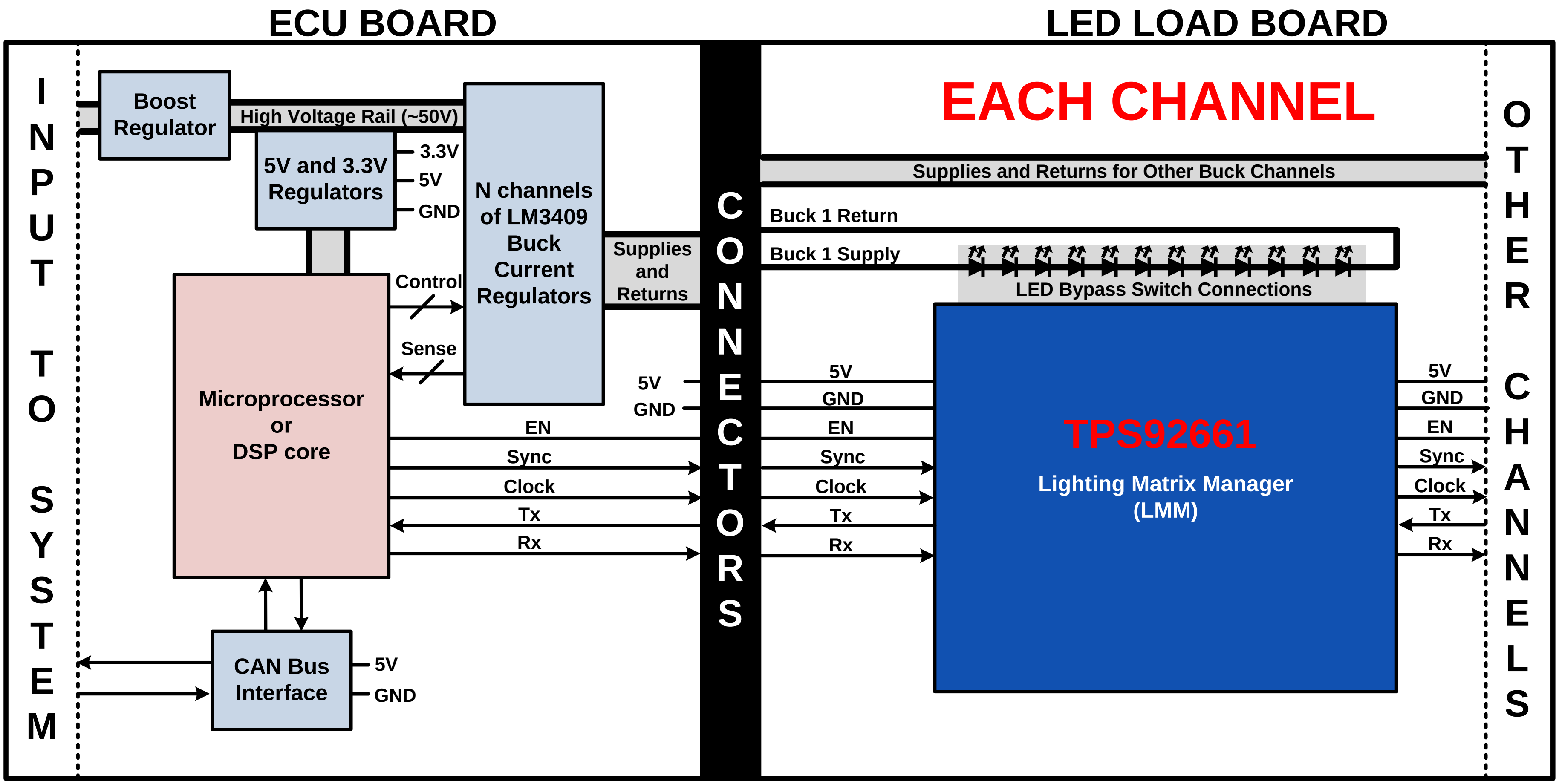
- IC can control ON/OFF times for each LED individually
- Simplifies control algorithm for the LMMs
- Seamless communication with system MCUs
- Simplifies system diagnostics and increases safety
- Cost effective routing with single layer metal-core PCB
- Small form factor with good thermal performance

Head Light Control Unit
Dual Stage Architecture

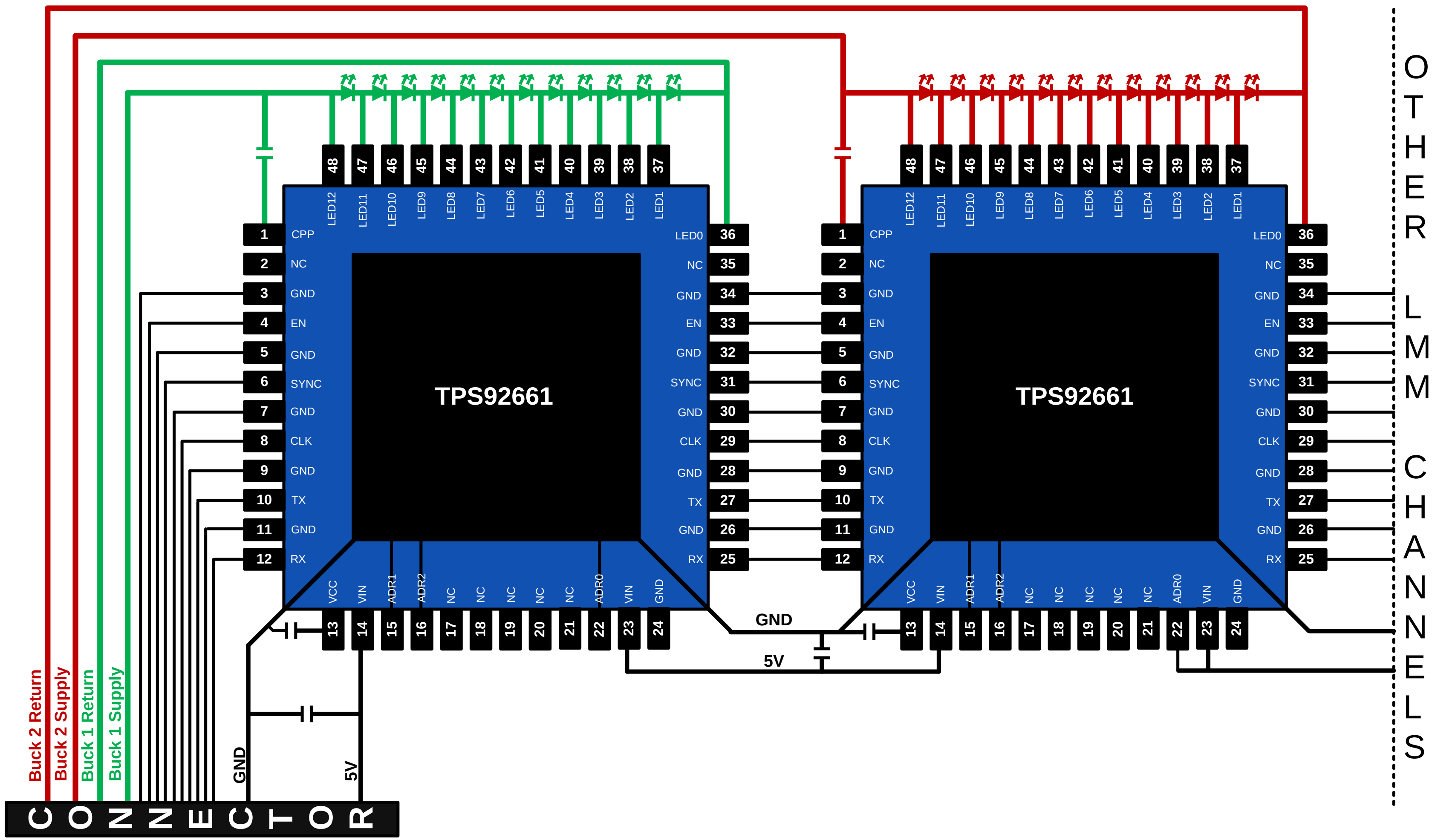
- Generating boosted battery voltage rail (voltage needs to fit to the longest LED string)
- **Buck Topology feasible for all LED Strings**
- Modular HW concept, slight loss in efficiency due to dual stage conversion



TPS92661 System Overview

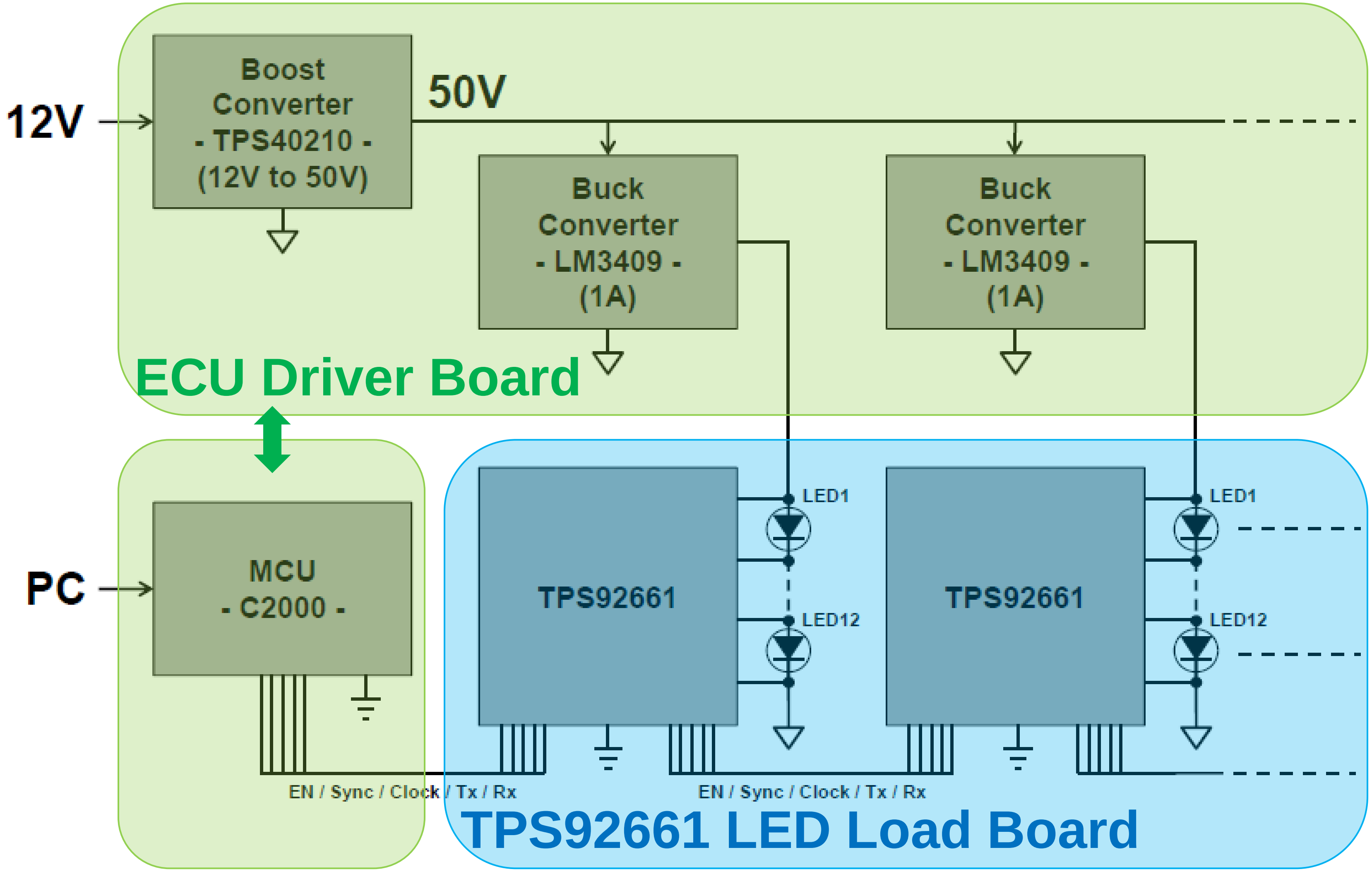


Metal Core LED Board with Multiple LMMs

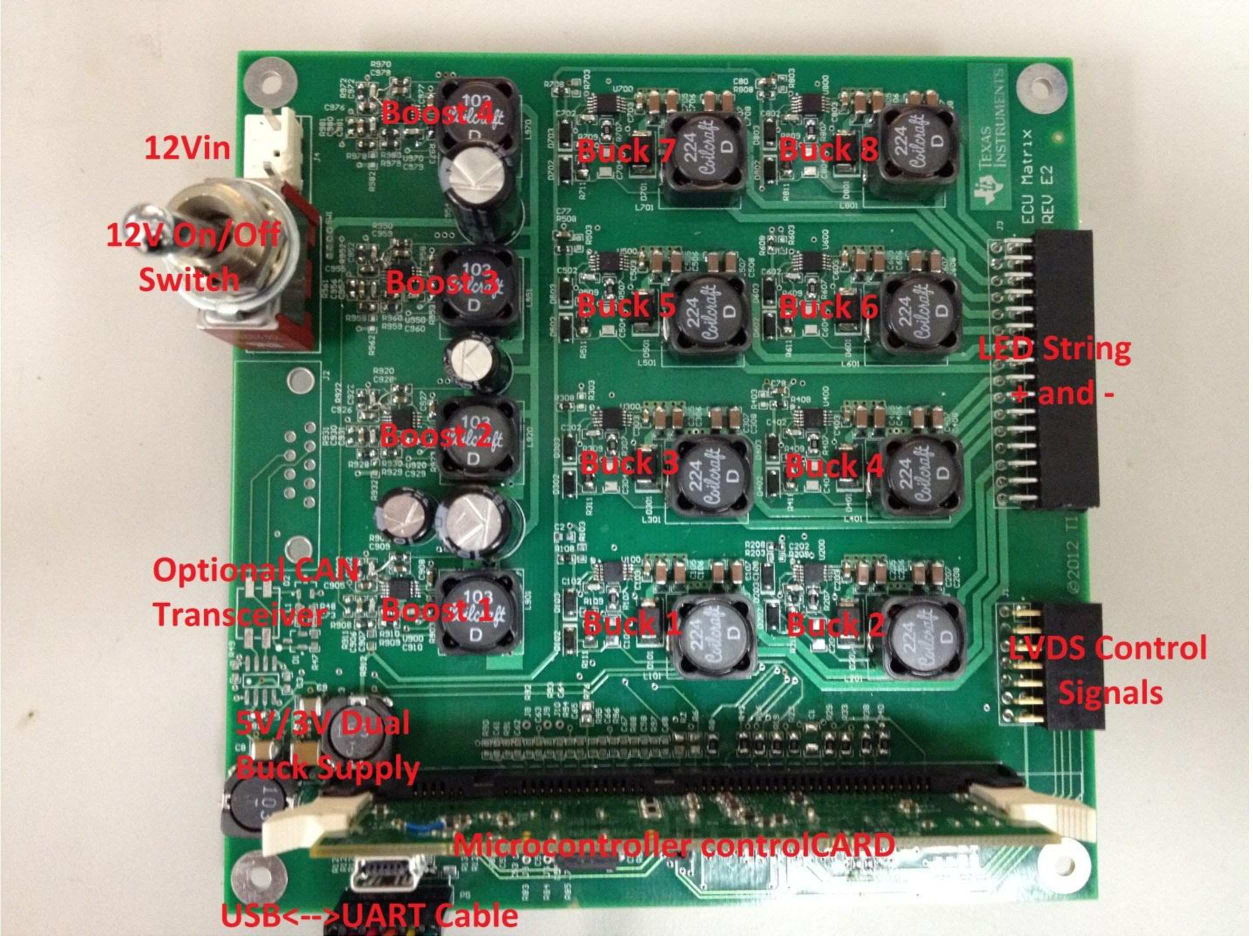


- LMM is on metal-core LED load board → has feed-through communications for routing on single side with only surface mount components.

TPS92661 Demo Kit (Simplified Diagram)



ECU Driver Board



<u>TI components inside</u>

C2000 based DIMM card

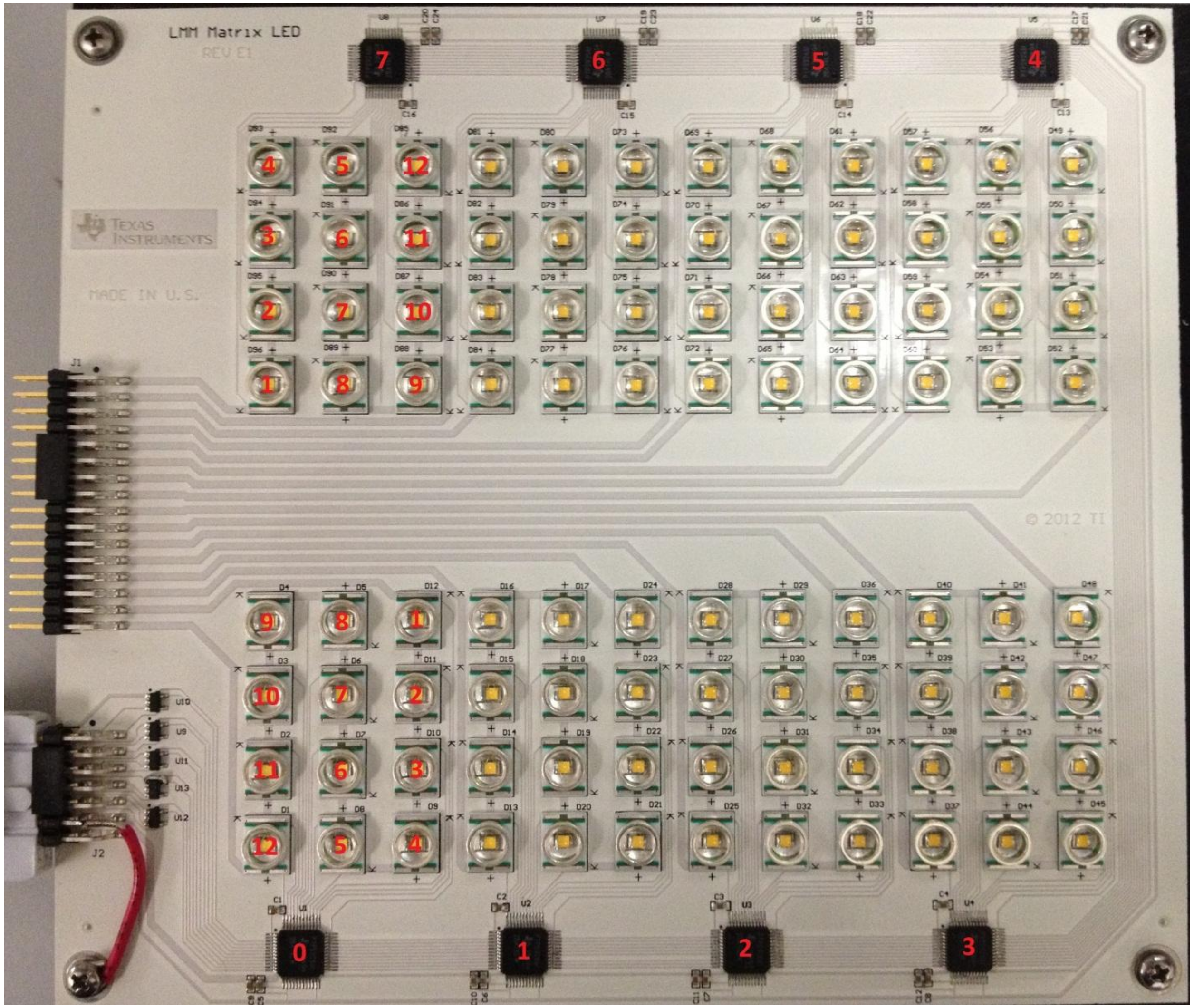
TPS40211 Boost converters (4)

LM3409QHV Buck converters (8)

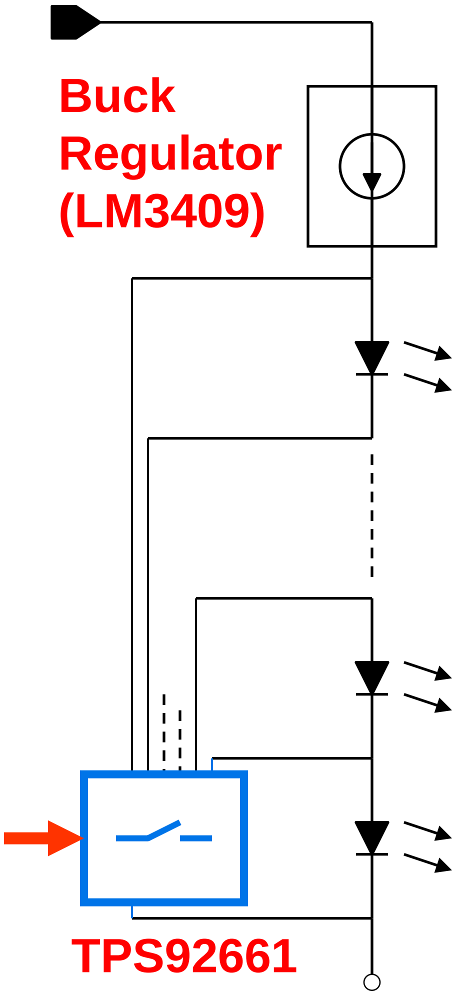
Simple Switcher (3.3V and 5V)

LVDS Transceivers

TPS92661 LED Load Board



TPS92661 (Lighting Matrix Manager)

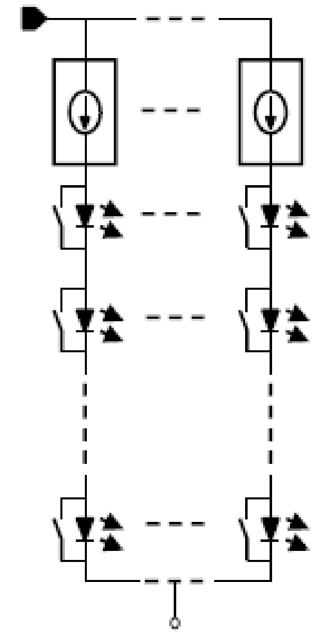


System configuration

- 12 LEDs per string
- 8 string max. per comm. line

Individual control of switches

- Separate PWM control of each
- 10 bit dimming resolution
- OPEN protection
- OPEN / SHORT fault diagnostic

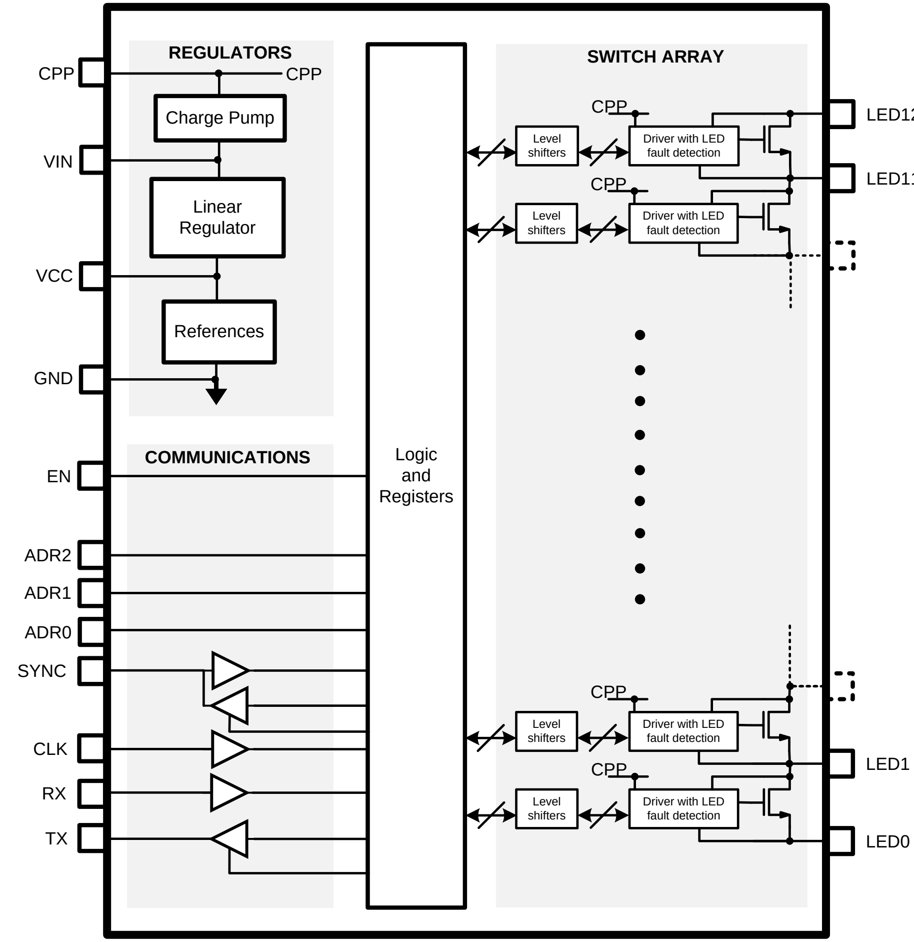


Other system features

- UART based comm. architecture
- Watchdog timer
- 3.3V or 5V comm. compatible
- Up to 65V LED stack voltage
- AEC-Q100 grade 1
- Thermally enhanced package
- Minimized complexity, part count, signal routing

TPS92661 Block Diagram

CPP	• Charge Pump output • Bypass with 0.1 uF (min.) ceramic cap. to LED12
VIN	• 5V power supply input for device • Bypass with 0.1 uF (min.) ceramic cap.
VCC	• Output of the on-board 3.3V LDO • Requires a 0.1 uF (min.) ceramic output cap. • Tie to VIN for 5V MCU systems
EN	• The device is active when EN is high, and in reset when EN is low
ADR	• Device address • Max. 8 devices per comm. line
SYNC	• Allows synchronization of multiple TPS92661s on the same network
CLK	• System Clock. • This clock is provided externally (by the MCU or an external oscillator) and is the primary clock for the TPS92661
RX	• UART received data pins
TX	• UART transmitted data pins • Requires a 100K pull-up



PWM Dimming (Frequency Configuration)

e.g. **6MHz Clock**
DPWR2 = 3
DDEC = 0

⇒ **PWM Dimming Freq.**
= 6M / 16 / 1 / 1024 = 366Hz

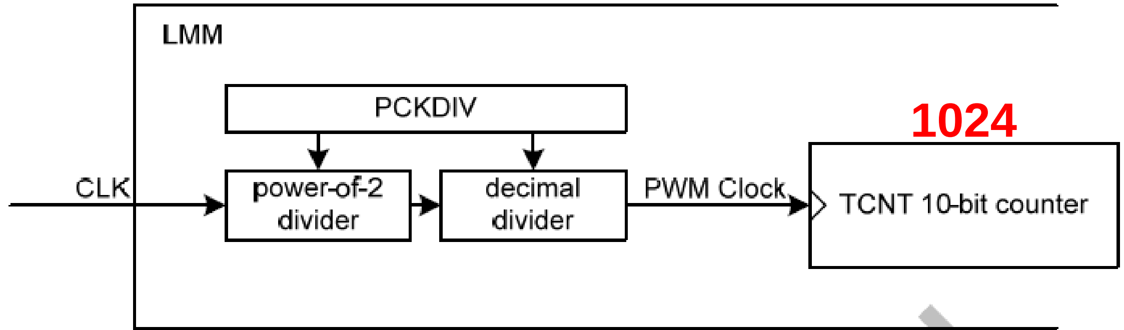


Figure 2: PWM Clock Divider

PWM Clock Divider Register (PCKDIV)

ADDR	REGISTER	D7	D6	D5	D4	D3	D2	D1	D0	DEFAULT
C0h	PCKDIV	RSVD	RSVD	DDEC[1:0]		RSVD	DPWR2[2:0]			00000011

DDEC[1:0]	Divide by:
0	1
1	3
2	5
3	reserved*

DPWR2[2:0]	Divide by:
0	2
1	4
2	8
3	16
4	32
5	64
6	reserved*
7	reserved*

PWM Dimming

LEDxOFF Register
800

LEDxON Register
250

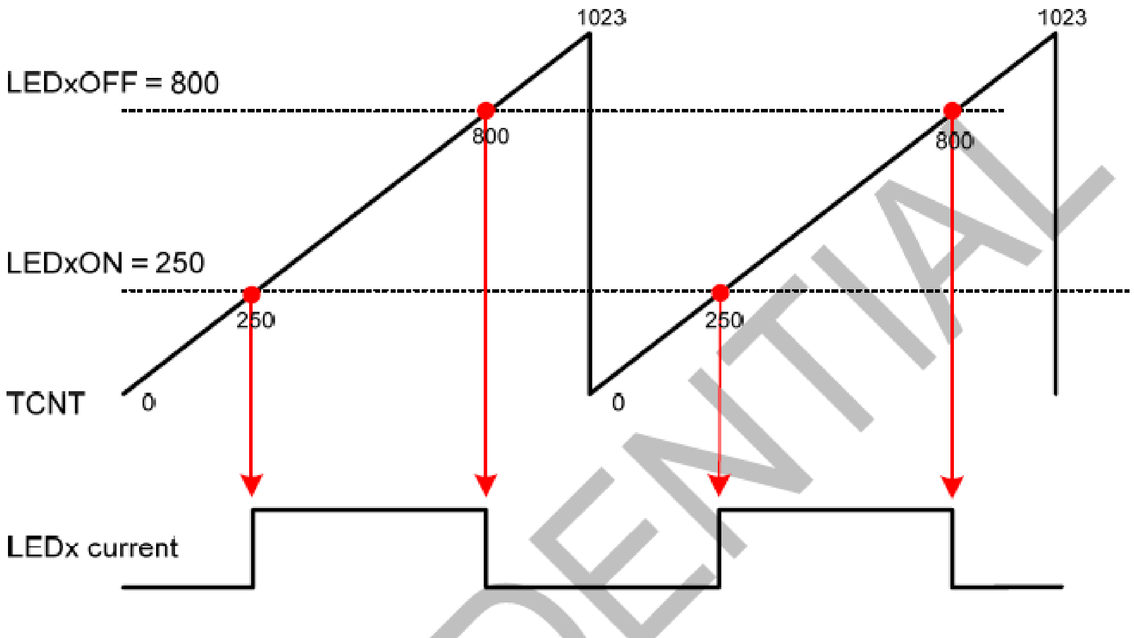


Figure 1: LED PWM Example

The 10-bit internal **PWM Period Counter (TCNT)** is compared against the LEDxON and LEDxOFF values.

- When TCNT reaches the programmed LEDxON value for a given LED, the corresponding bypass switch is turned off to force current through the LED.
- Likewise, when TCNT reaches the programmed LEDxOFF value, the bypass switch is turned on to turn off the LED.

PWM Dimming (Register Map)

LED ON Registers						
00h	LED1ONL	LED1ON[7:0]				00000000
01h	LED2ONL	LED2ON[7:0]				00000000
02h	LED3ONL	LED3ON[7:0]				00000000
03h	LED4ONL	LED4ON[7:0]				00000000
04h	LED1_4ONH	LED4ON[9:8]	LED3ON[9:8]	LED2ON[9:8]	LED1ON[9:8]	00000000
05h	LED5ONL	LED5ON[7:0]				00000000
06h	LED6ONL	LED6ON[7:0]				00000000
07h	LED7ONL	LED7ON[7:0]				00000000
08h	LED8ONL	LED8ON[7:0]				00000000
09h	LED5_8ONH	LED8ON[9:8]	LED7ON[9:8]	LED6ON[9:8]	LED5ON[9:8]	00000000
0Ah	LED9ONL	LED9ON[7:0]				00000000
0Bh	LED10ONL	LED10ON[7:0]				00000000
0Ch	LED11ONL	LED11ON[7:0]				00000000
0Dh	LED12ONL	LED12ON[7:0]				00000000
0Eh	LED9_12ONH	LED12ON[9:8]	LED11ON[9:8]	LED10ON[9:8]	LED9ON[9:8]	00000000

LED OFF Registers						
20h	LED1OFFL	LED1OFF[7:0]				00000000
21h	LED2OFFL	LED2OFF[7:0]				00000000
22h	LED3OFFL	LED3OFF[7:0]				00000000
23h	LED4OFFL	LED4OFF[7:0]				00000000
24h	LED1_4OFFH	LED4OFF[9:8]	LED3OFF[9:8]	LED2OFF[9:8]	LED1OFF[9:8]	00000000
25h	LED5OFFL	LED5OFF[7:0]				00000000
26h	LED6OFFL	LED6OFF[7:0]				00000000
27h	LED7OFFL	LED7OFF[7:0]				00000000
28h	LED8OFFL	LED8OFF[7:0]				00000000
29h	LED5_8OFFH	LED8OFF[9:8]	LED7OFF[9:8]	LED6OFF[9:8]	LED5OFF[9:8]	00000000
2Ah	LED9OFFL	LED9OFF[7:0]				00000000
2Bh	LED10OFFL	LED10OFF[7:0]				00000000
2Ch	LED11OFFL	LED11OFF[7:0]				00000000
2Dh	LED12OFFL	LED12OFF[7:0]				00000000
2Eh	LED9_12OFFH	LED12OFF[9:8]	LED11OFF[9:8]	LED10OFF[9:8]	LED9OFF[9:8]	00000000

Each TPS92661 can control Max. 12 LEDs individually

The 10 bits **LED ON** registers **(LEDxON)** for each individual LED

The 10 bits **LED OFF** registers **(LEDxOFF)** for each individual LED

Glitch-Free Dimming Operation

To help eliminate glitches in the LED current during register updates.

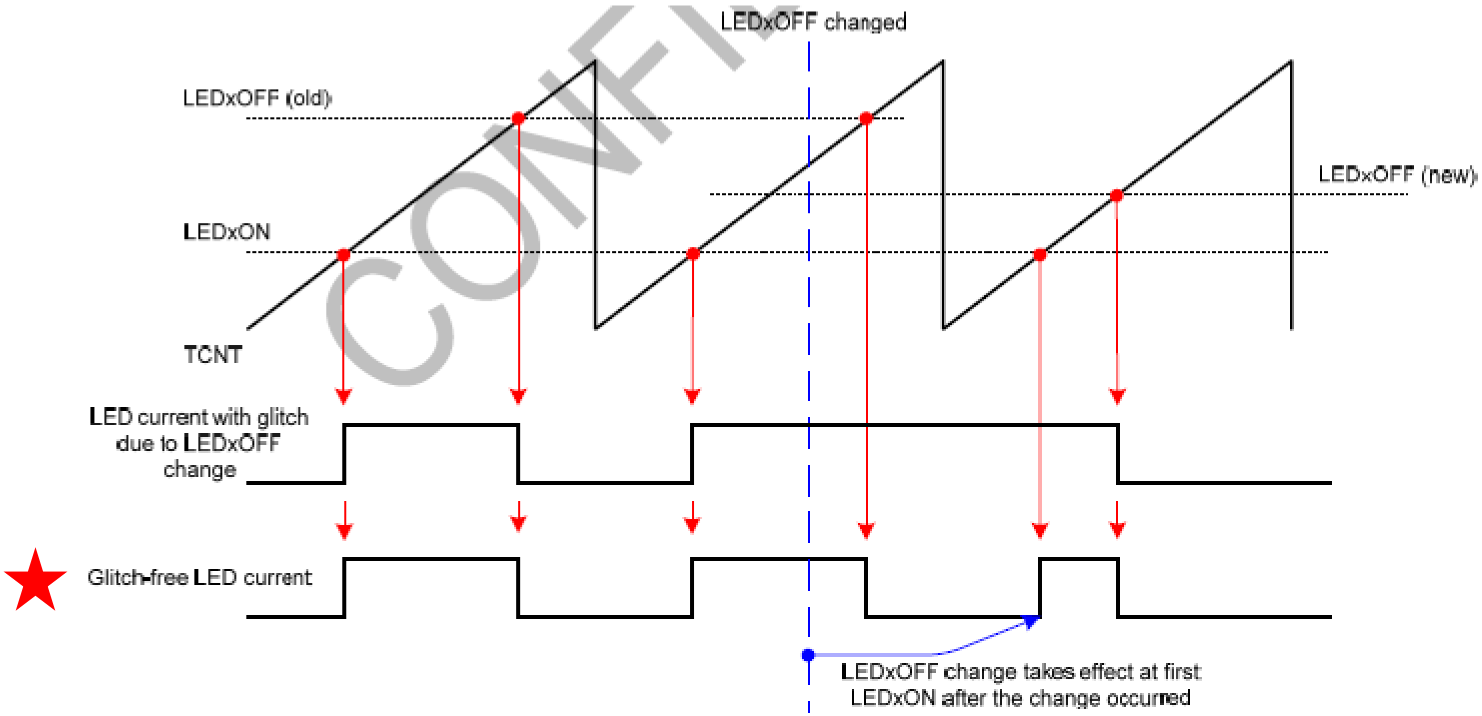
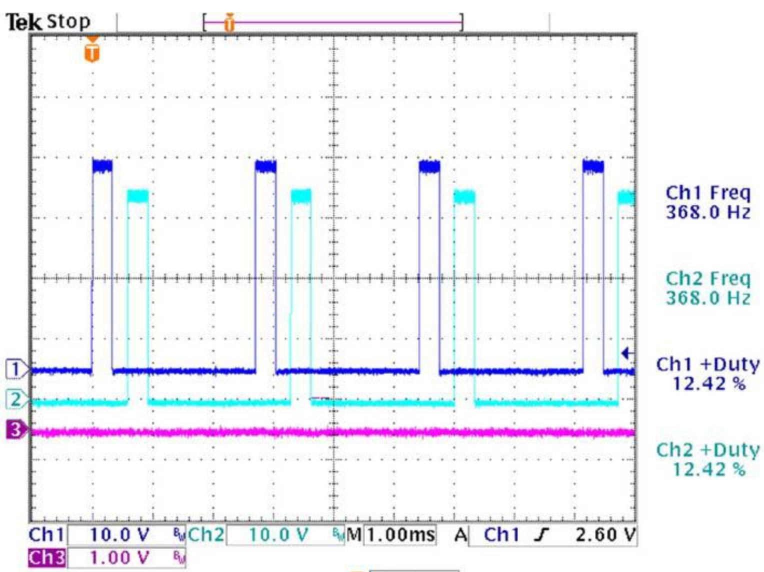


Figure 4: Glitch-Free LED Dimming Operation

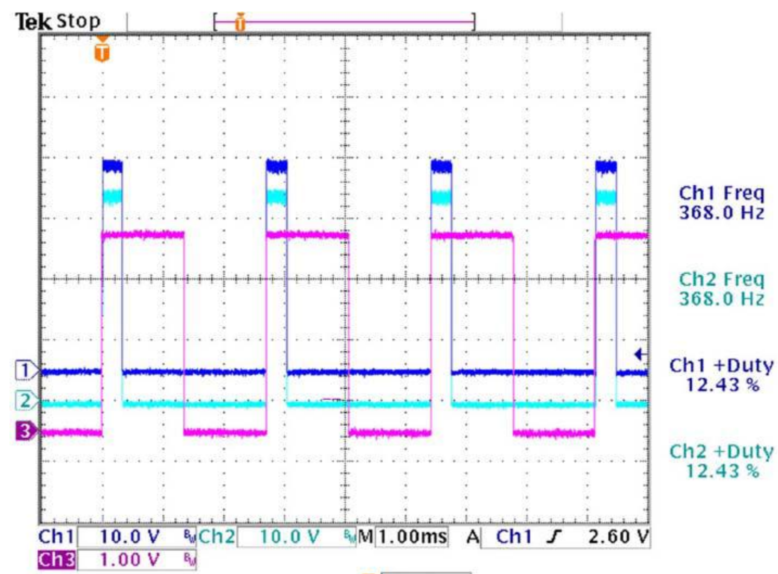
PWM Synchronization

In order to correctly synchronize multiple TPS92661s on the same network, two conditions must be met:

1. All TPS92661s must be clocked by the same clock on the CLK pin
2. All TPS92661s must be programmed with the same PWM clock dividers (PCKDIV)



Non-Synchronized LED Channels

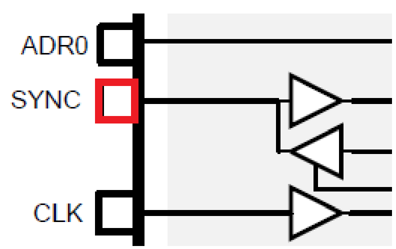


Actively Synchronized LED Channels

Dark blue: 1st TPS92661

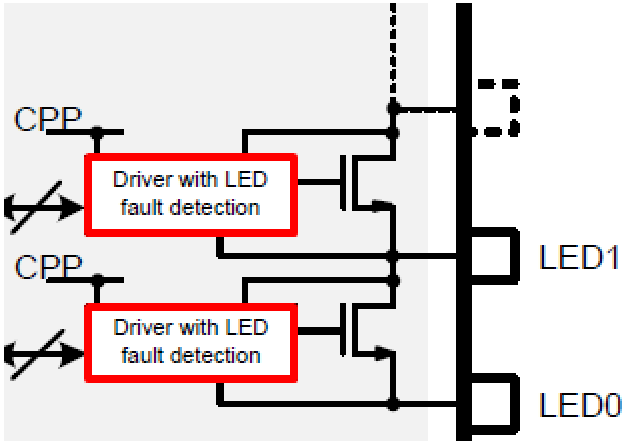
Light blue: 2nd TPS92661

Purple: signal at SYNC pin



Fault Protection & Diagnostic

Diagnostic Registers				
E0h	FAULTL	FAULT[8:1]		00000000
E1h	FAULTH	RESERVED	FAULT[12:9]	00000000



Diagnostic

- An internal comparator monitors the drain to source voltage of the internal switch.

OPEN Fault

- If the voltage > 6.3V

1. The switch off signal is overridden and the switch is turned on.
2. It will set the corresponding bit in the FAULT register.

SHORT Fault

- If the voltage < 1.7V

1. It will set the corresponding bit in the FAULT register.

TPS92630 – 3 channel 150mA Constant Current Linear LED Driver

Features

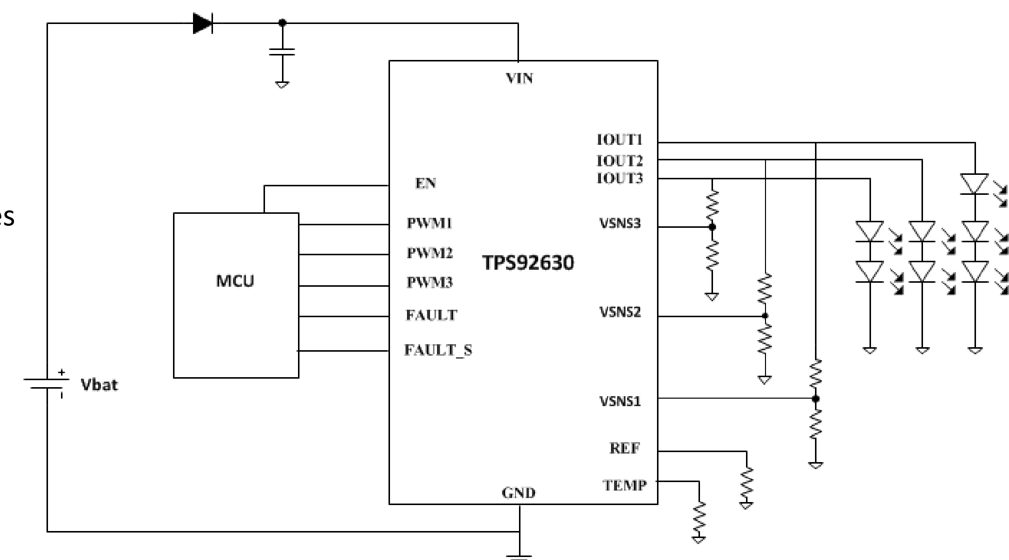
- AEC-Q100 Qualified
- 3 Channel LED Driver with Analog and PWM dimming
- Wide input voltage range: 5 – 40V
- Adjustable const. output current set by reference resistor
  - Max. Current: 150mA per channel
  - Accuracy (Ioutx > 30mA): ± 1.5% per channel; ± 2.5% per device
- Support channel parallel connection both within IC and among multi-ICs
- Low Dropout Voltage
  - Typ. Dropout: 400mV @ 60mA per channel
  - Max. Dropout: 900mV @ 150mA per channel
- Independent PWM Dimming per channel
  - High Voltage Tolerant
  - Max. dim. freq.: 2kHz
  - ON/OFF Delay time: 15us (typ) / 25us (typ)
- Open & Shorted LED Detection with deglitch timer
- Fault pin for open, short and thermal shutdown failure reporting, allowing parallel bus connection up to 15 devices
- LED String Voltage Feedback per channel for Single LED Short Detection and Separate Fault pin for failure report
- Pass slow power up test (0.5V/min) with no latch
- Two Options for device temperature information
  - TPS92630 – Current fold back to prevent thermal shutdown, with programmable threshold
  - TPS92631 – Analog voltage output proportional to the device temperature
- Operating Junction Temp. Range: -40 C to +150 C
- Thermally enhanced PWP package (HTSSOP - 16)

Applications

- **Rear Light – Tail/Stop Light, Turn Light, Fog Light, Reverse Light**
- **Front Light – Position light, Daytime Running Light, Turn Light**
- **Interior Light**

Benefits

- **Common Cathode LED Connection and High Side Current Sense**
- **Thermal Current Foldback**
- **Full Diagnostic and Single LED Short Detection**
- **Global EN and Individual PWM dimming**



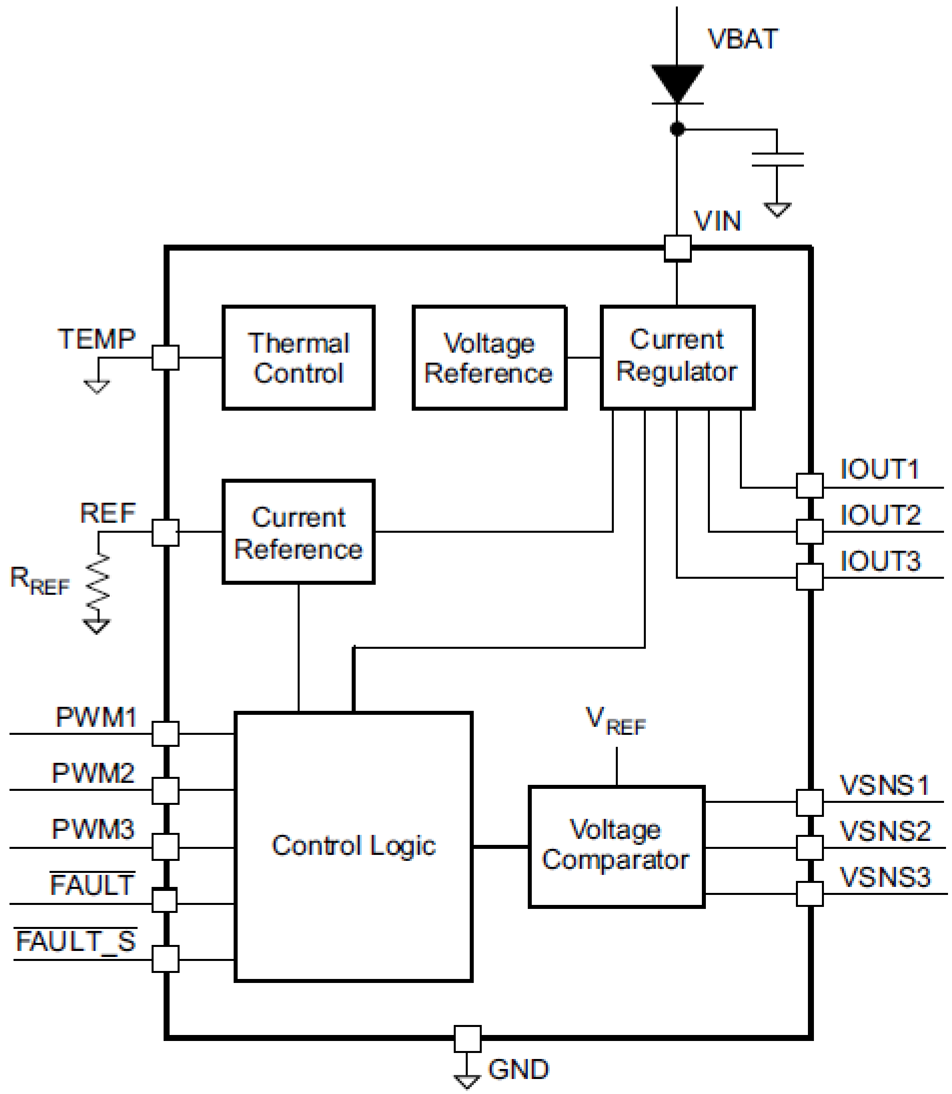
Value Proposition

Features	Benefits
High side current sense	Common Cathode LED connection to support lower risk and cost system implementation
Global EN and each channel individual PWM dimming	Easy control and separate brightness adjustment for each channel
Thermal current foldback with programmable threshold	Avoid the device from overheating and prevent LED from flickering due to rapid thermal changes
Full Diagnostic and Single LED short Detection	Offer design flexbility to meet different countries regulation in terms of lamp failure detection
Fault and FaultS pins can support bus connection up to 15 devices	Multi devices works together without additional MCU control, and avoid complex control logic for fault reaction
Open and Shorted LED detection with Deglitch, and no latch during slow power up (0.5V/min)	Robust Diagnostic for Fault, and avoid false detection and reaction

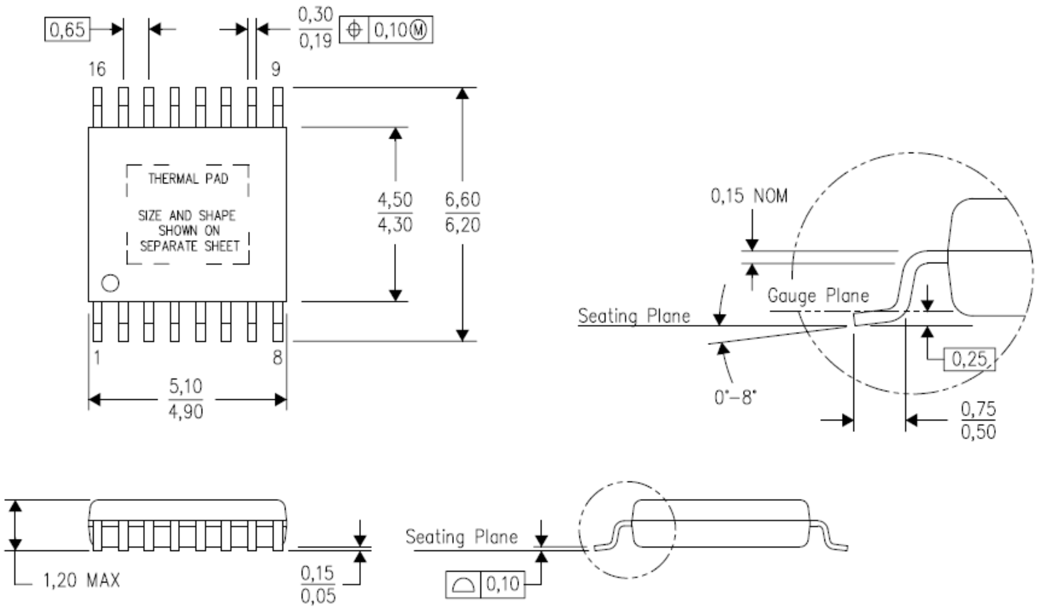
Value Proposition against discrete solution

System Parameter	TPS92630	Discrete
Solution size	Highly integrated	Large number of discrete components and PCB wiring
Constant Current	YES, maintain high level of matching between channels and ICs with varying voltage and different number of LEDs	Varying with battery voltage; Need to manage LED binning logistics
Diagnostics	Open, Short, Single LED Short, Thermal Shutdown. Support different fault reporting scheme with MCU or no MCU	Not available or very cumbersome to implement
Thermal management	Thermal monitor to reduce current to avoid too much power dissipation at high temperature. Programmable Temperature threshold	No; Or additional temperature sensor needed
Flexibility	Can be easily designed to support different LED configurations. 3 output channels can be paralleled to support high current single LED string	Require redesign for every new projects

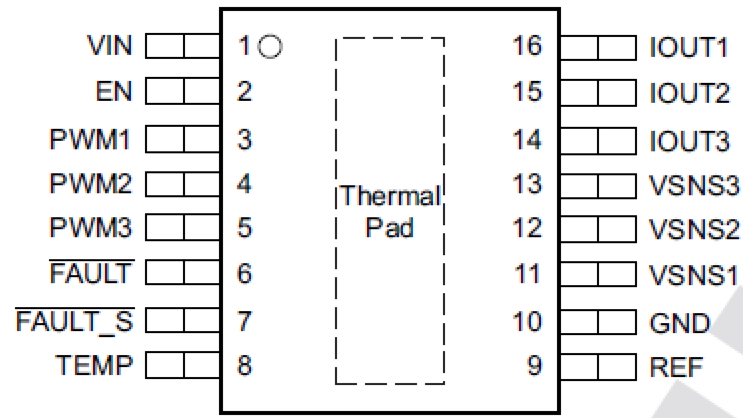
Internal Block Diagram



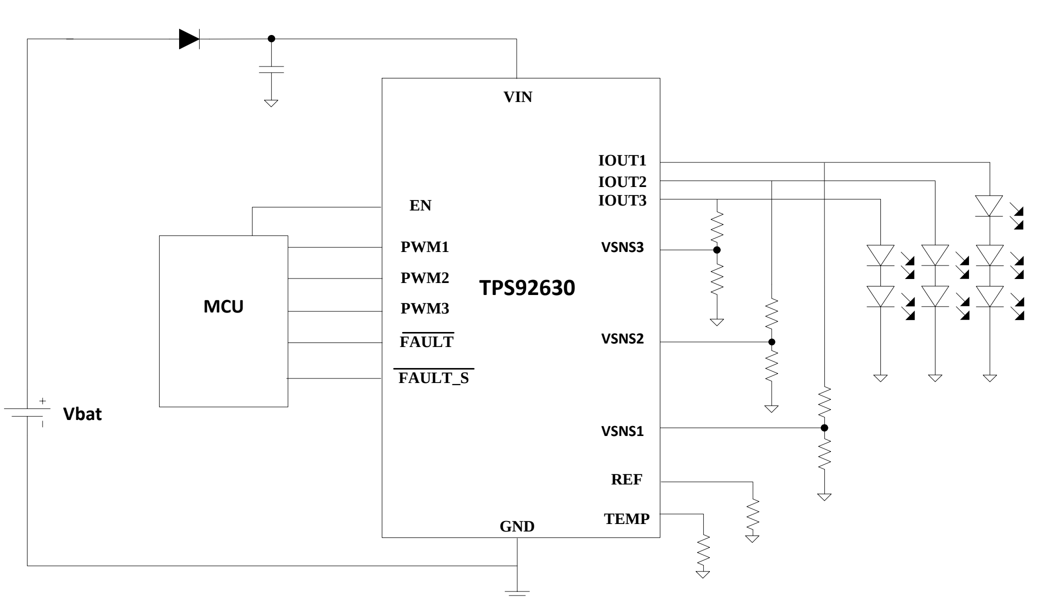
Package Pin Assignment

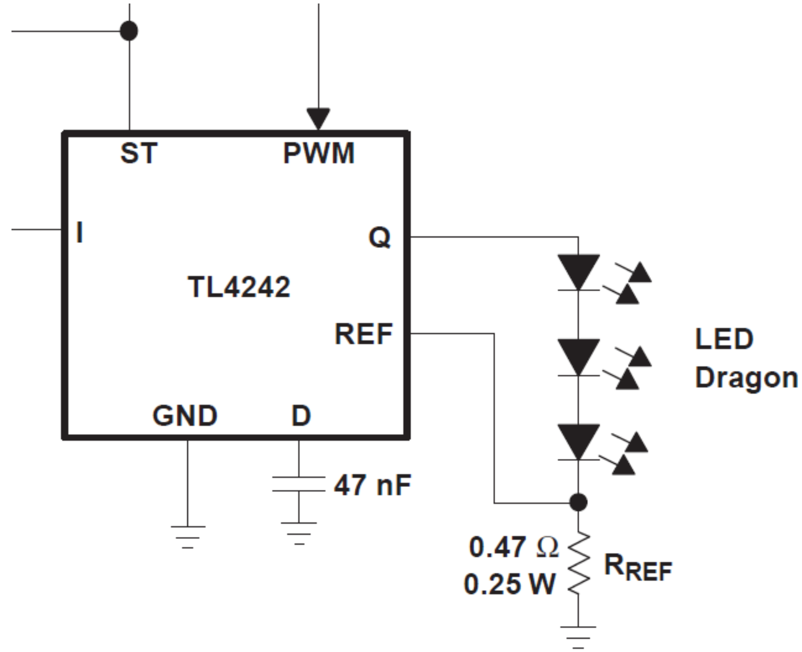


16-Terminal PDSO With PowerPAD™ Thermal Pad
PWP Package
(Top View)



High Side Current Sense

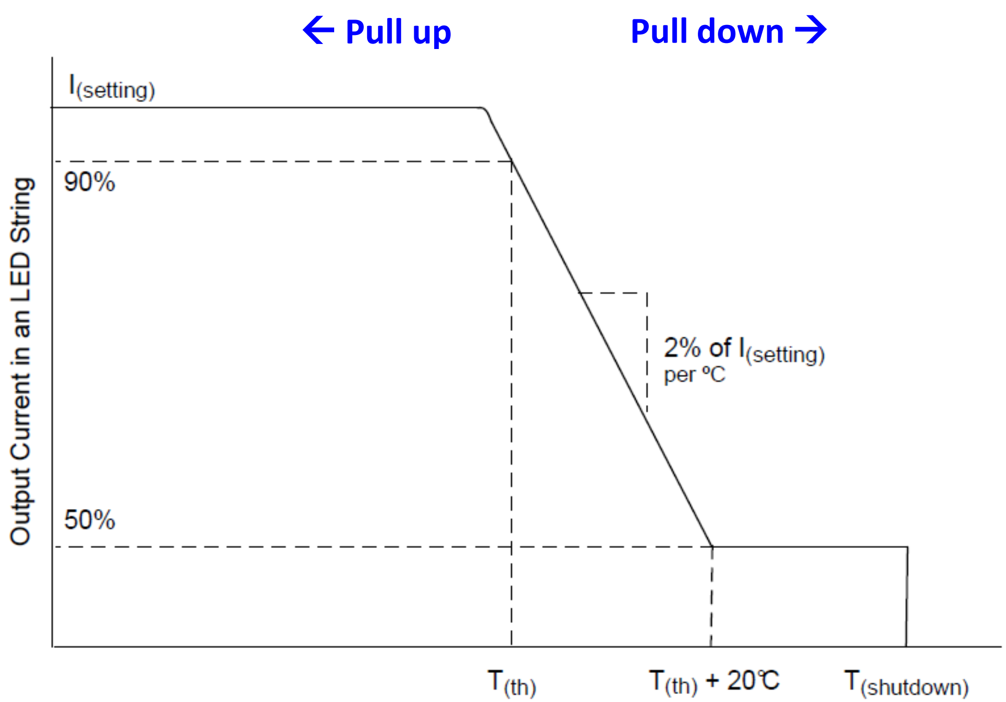




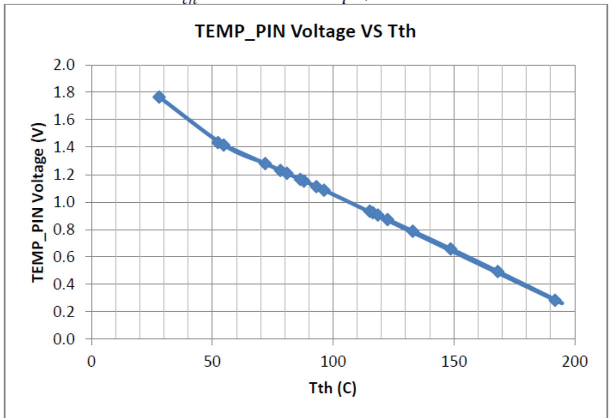
- Saving one wire, cost down.
- Easy layout, needn't to consider FB wire noise.
- No risk for LED over current cause by FB wire short to GND

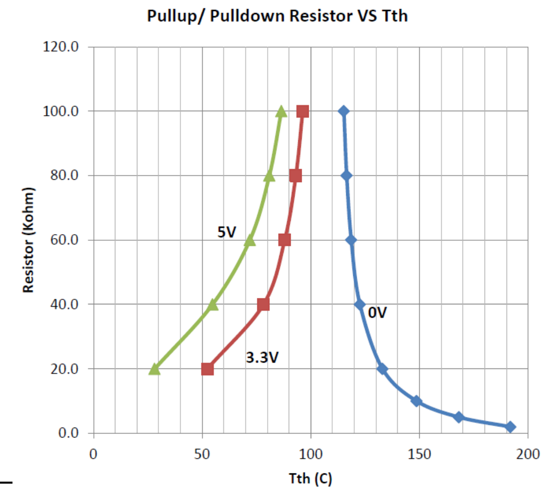
Thermal Current Foldback

In linear LED solution, thermal dissipation is critical. TPS92630 integrates thermal shutdown protection to avoid IC from overheating. In addition, to prevent LEDs from flickering due to rapid thermal changes, a programmable thermal current foldback feature is included to reduce power dissapation at high junction temperature



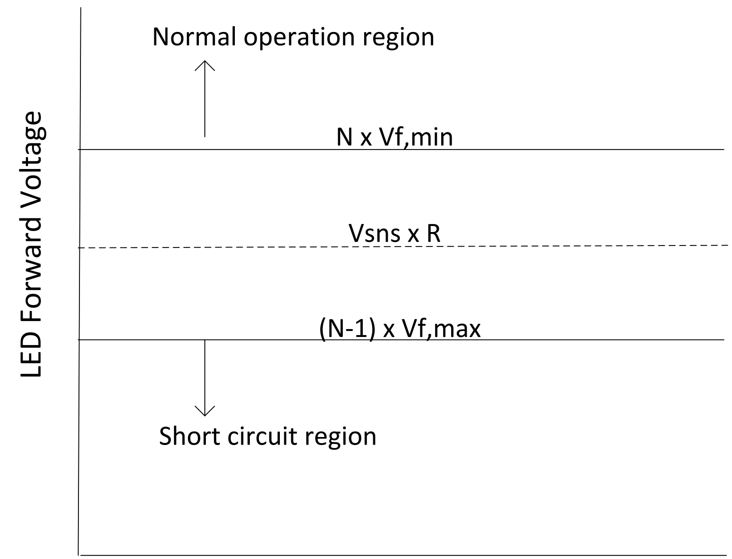
$$T_{th} = -121.7Vtemp + 228.32$$



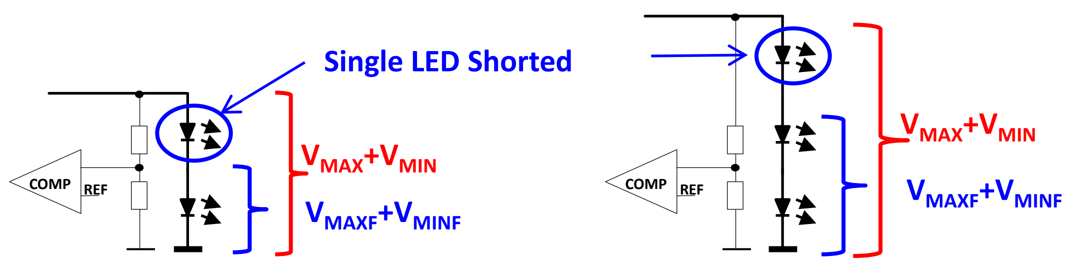


Single LED Short

- **Vf,max -- maximum forward voltage of LED used**
- **Vf,min -- minimum forward voltage of LED used**
- **N -- number of LED used in a string**
- **R -- resistor divider ratio**
- **Vsns -- internal reference voltage of comparators**



Example – Philips SnapLED 70&150:



V_{MAX} = 2 * 2.91V = 5.82V

V_{MIN} = 2 * 2.43V = 4.86V

V_{MAXF} = 2.91V

V_{MINF} = 2.43V

V_{MAX} = 3 * 2.91V = 8.73V

V_{MIN} = 3* 2.43V = 7.29V

V_{MAXF} = 2 * 2.91V = 5.82V

V_{MINF} = 2* 2.43V = 4.86V

LED Short Diagnostic

Different OEMs have different requirements on exterior LEDs' operation when different LED short conditions happen.

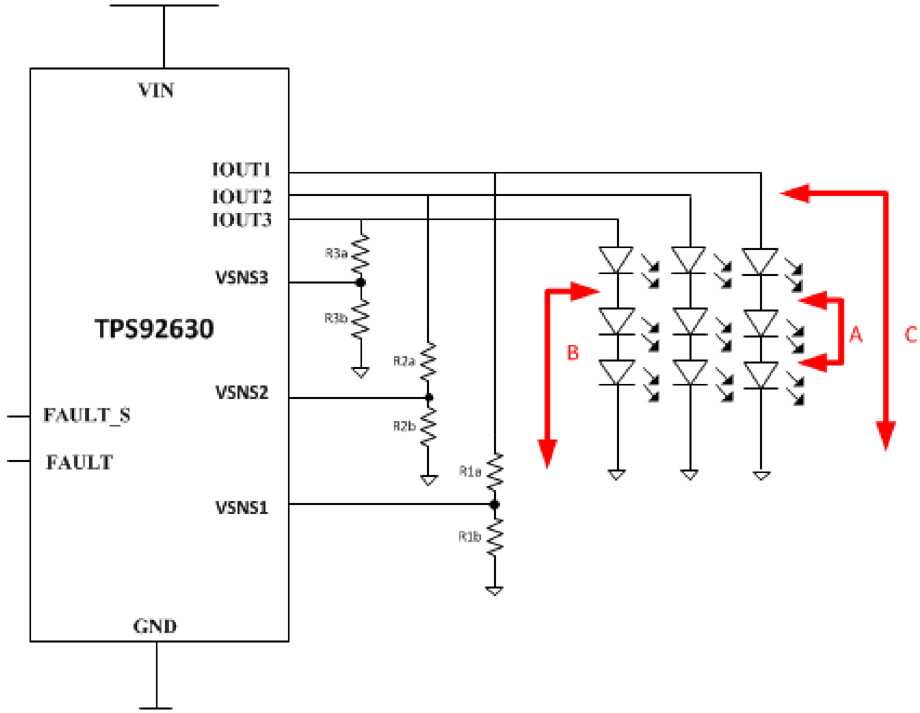
TPS92630 has a dedicated fault pin (FAULT_S) for single LED short failure and general fault pin (FAULT), which allow the maximum flexibility based on all requirements and application conditions

- **When a Single or more LED are shorted (Vout still over 0.9V) in a string [A & B]**

    1) **FAULT_S will pull low and MCU will be reported with the failure, the faulted channel will remain sourcing current. Actions will be taken by MCU to turn off channels through EN/PWM pin, or ignore.**

    2) **No MCU: if FAULT_S is floating, no action will be taken. If FAULT_S is tied to FAULT , all output channels will be shut down together**

- **When an entire string of LED is shorted (Vout <0.9V) [C], FAULT will pull low and all channel will be turned off. When FAULT pin is tied high, only faulted channels will be shut down.**



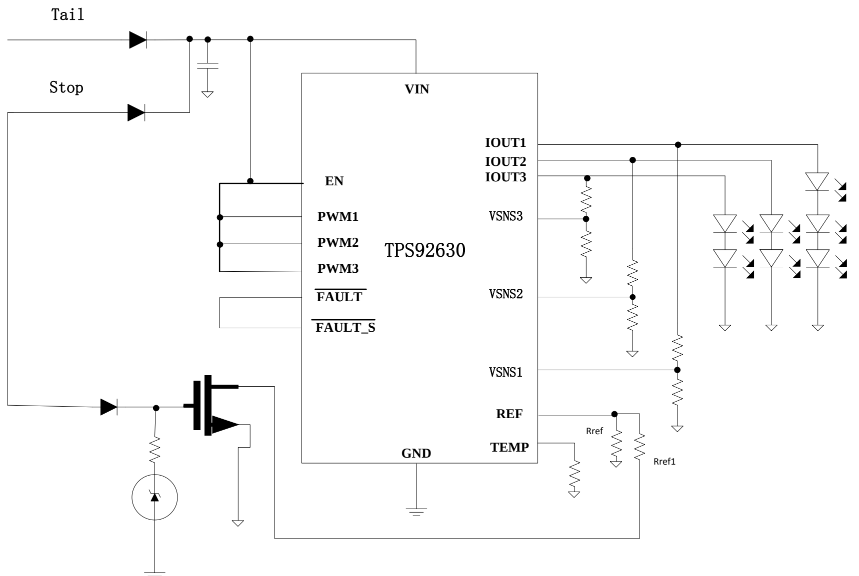
Full Diagnostic

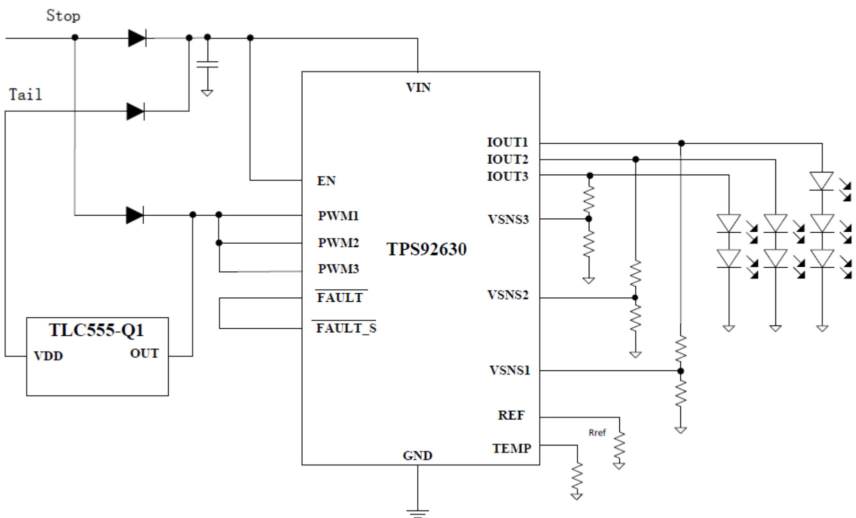
Table 1. Fault Table(1)(2)

Failure Mode	Judgement Condition			Diagnostic Output Terminals	Action	FAULT and FAULT_S(3)	Device Reaction	Failure Removed	Self-Clearing
	Detection VIN Voltage	Channel Status	Detection Mechanism						
Short circuit: 1 or several LED strings	$V_{(VIN)} > 5$ V	On	$V_{(IOUTx)} <$ 0.9 V	FAULT	Pulled low	Externally pulled high	Failing strings turned off, other channels on	Toggle EN, power cycle	No
						Floating	All strings turned OFF	Toggle EN, power cycle	
Single-LED short circuit: 1 or several LED strings	$V_{(VIN)} > 9$ V	On	$V_{(VSNSx)} <$ 1.222 V	FAULT_S	Pulled low	Externally pulled high	All strings stay ON	Toggle EN, power cycle	No
						Floating	All strings stay ON	Toggle EN, power cycle	
Open load: 1 or several LED strings	$V_{(VIN)} > 5$ V	On	$V_{(VIN)} - V_{(IOUTx)} <$ 100 mV	FAULT	Pulled low	Externally pulled high	All strings stay ON		Yes
						Floating	Failing string stays ON, other channels turned OFF		
Short to battery: 1 or several LED strings	$V_{(VIN)} > 5$ V	On or off	$V_{(VIN)} - V_{(IOUTx)} <$ 100 mV	FAULT	Pulled low	Externally pulled high	All strings stay ON		Yes
						Floating	Failing string stays ON, other channels turned OFF		
Thermal shutdown	$V_{(VIN)} > 5$ V	On or off	Temperature > 170°C	FAULT	Pulled low	Externally pulled high	All strings turned OFF	Temperature < 155°C	Yes
						Leave open			
Thermal foldback	$V_{(VIN)} > 5$ V	On or off	Temperature > 110°C	N/A	None	N/A	All strings with reduced current	Temperature < 100°C	Yes
Reference resistor open or shorted	$V_{(VIN)} > 5$ V	On or off	$R_{REF} > 57$ kΩ or $R_{REF} < 350$ Ω	FAULT	Pulled low	N/A	All strings turned OFF	Toggle EN, power cycle	No

(1) With diagnostic terminals FAULT and FAULT_S tied high externally, pullup must be strong enough to override internal pulldown.
(2) To achieve single-LED short circuit to turn off all strings, FAULT_S and FAULT terminals must be connected together.
(3) Pulling FAULT and FAULT_S high externally changes the behavior of the device reaction. If not externally forced high, the device pulls the terminals low based on the failure mode.

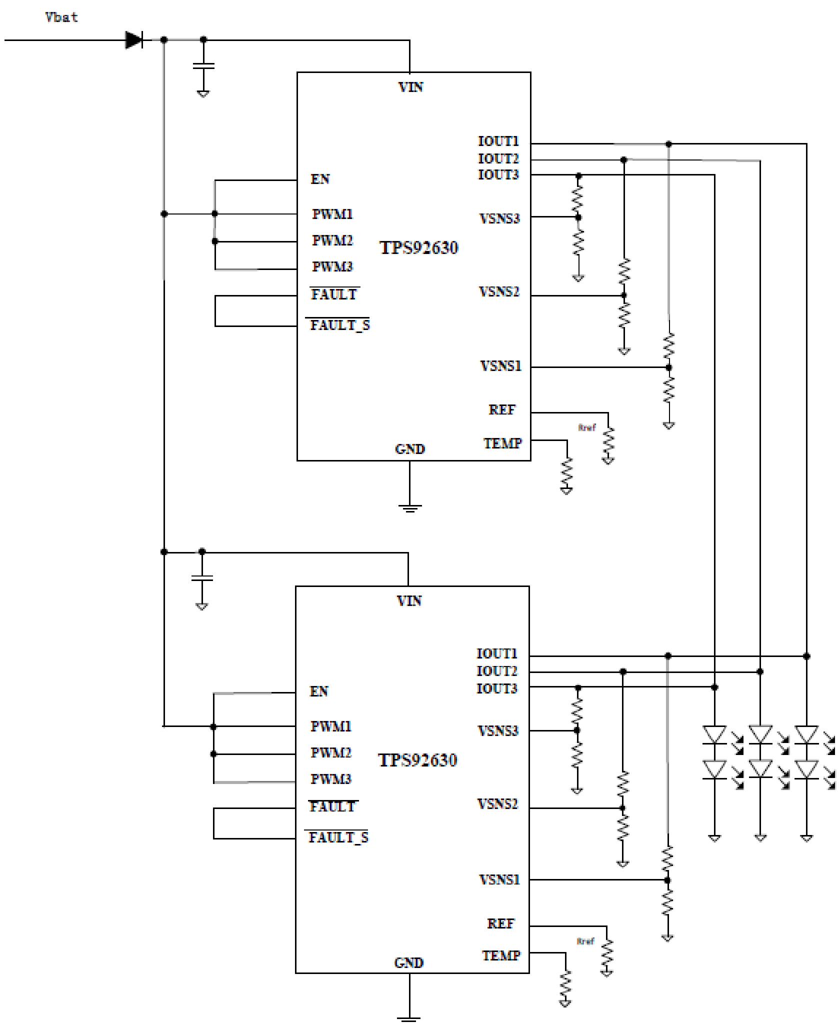
Two Brightness Level for Tail/Stop

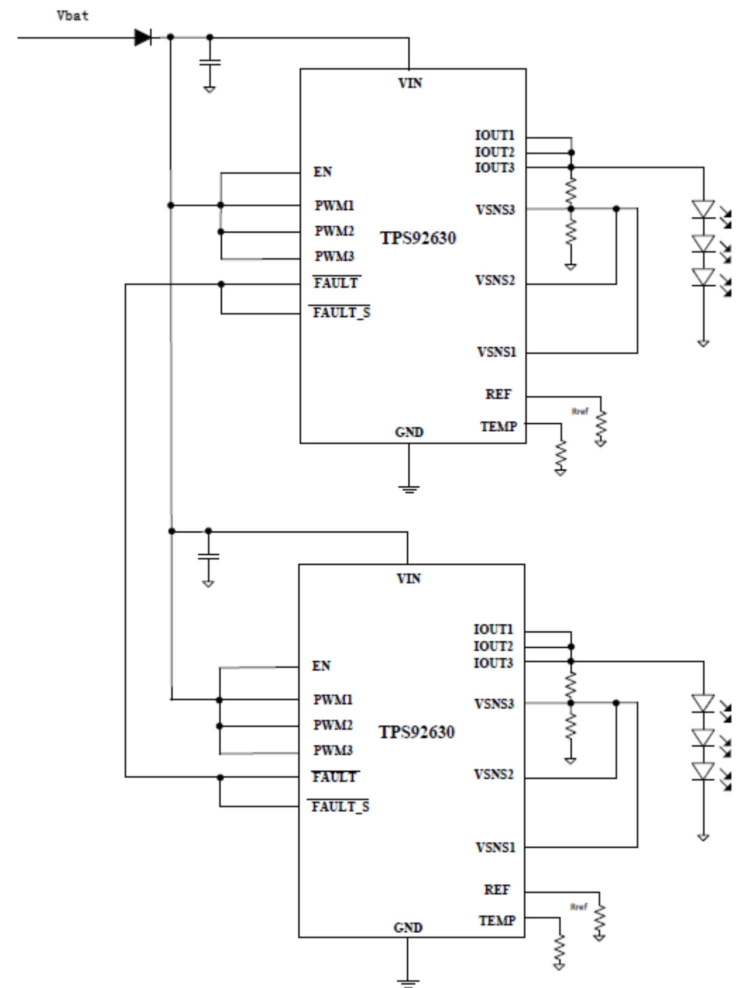




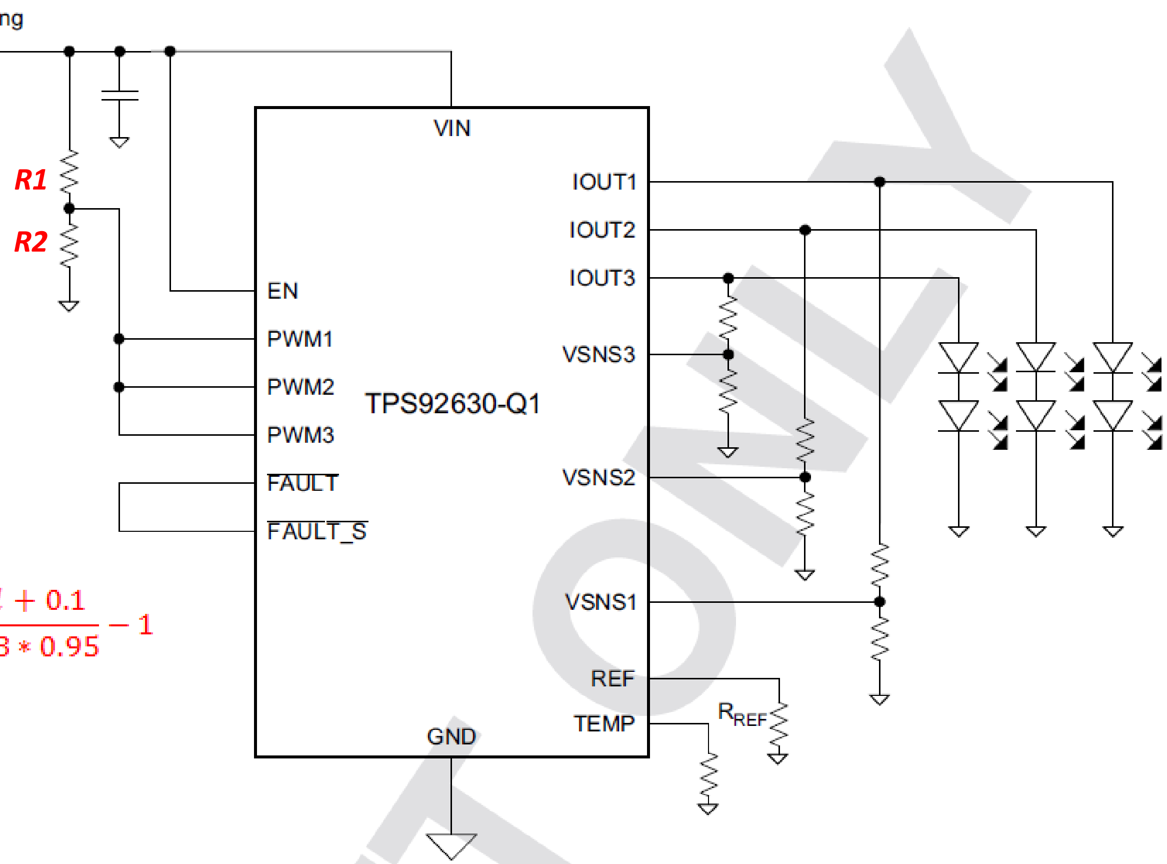
$$Ioutx = \frac{Vref \times Gi}{Rref//Rstop}$$

Parallel Connection for Multi IC or Multi Channel





High Side Driver for PWM Dimming



- If system has no MCU or PWM, you can use high side driver to do the dimming directly. When use the high side driver to do PWM dimming, resistor divider must be put in the PWM pin in case of the current over shot during rising PWM edge.
- Firstly, you need to measure the Vin voltage when high side signal is low, Vinl.
- Then get the ratio for R1/R2 is: $\frac{R1}{R2} = \frac{Vinl + 0.1}{1.178 * 0.95} - 1$
- Finally you can choose the suitable resistor for the application.

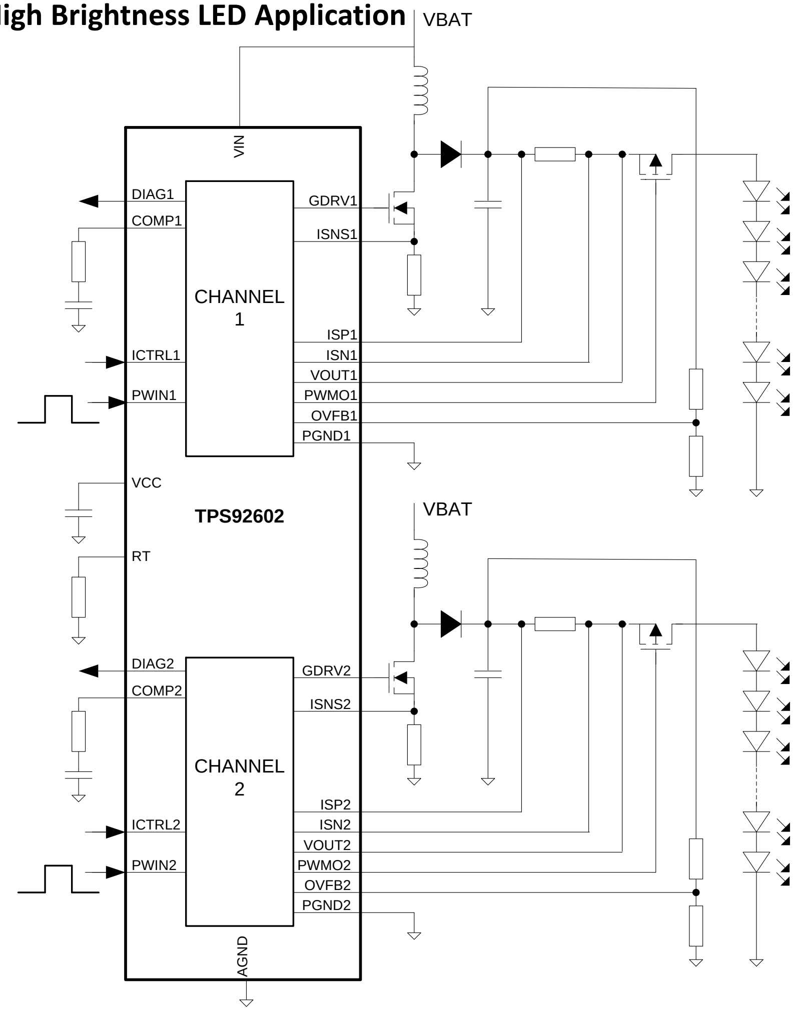
TPS92602 – 2 channel High Side Current Sense Switching LED Driver

Features

- AEC-Q100 Qualified
- Input Voltage: 4 ~ 40V (45V abs. max.)
  Output Voltage: 4 ~ 75V (80V abs. max.)
- Each channel is fixed frequency current mode controller with integrated slope compensation, operating 180C out of phase
- Each channel can work independently to support multi topology including buck, boost, buck-boost, SEPIC, Flyback
- Each Channel Const. Current Loop and Const. Voltage Loop
- Linear Analog Dimming with high side current sense
  - 150mV or 300mV Sense Voltage (EERPOM option)
  - +/- 6mV offset (achieving ~ 4% or 2% LED current accuracy)
- Linear PWM Dimming with integrated high side PMOS-FET Driver: 200Hz to 2KHz
- Internal voltage reference (2.2V +/-5%) for Vout Sense in Const. Voltage Loop
- Integrated low side NMOS-FET driver
- Programmable switching frequency (100 ~ 600kHz) and external synchronization
- Dedicated DIAG output pin for each channel Diagnostic
  - Pull low for LED Open and Output Over Voltage (Const. Voltage Loop and Auto-recovery)
  - Pull high for Output Short Circuit to GND and Output Over Current
  - Linear monitoring LED current during non-failure condition
- Protection
  - Input Under Voltage (Auto-recovery) & Over Voltage Protection
  - Thermal Shutdown (Auto-recovery)
- Operating Junction Temp. Range: -40 C to +150 C
- Thermally enhanced PWP package (HTSSOP - 28)

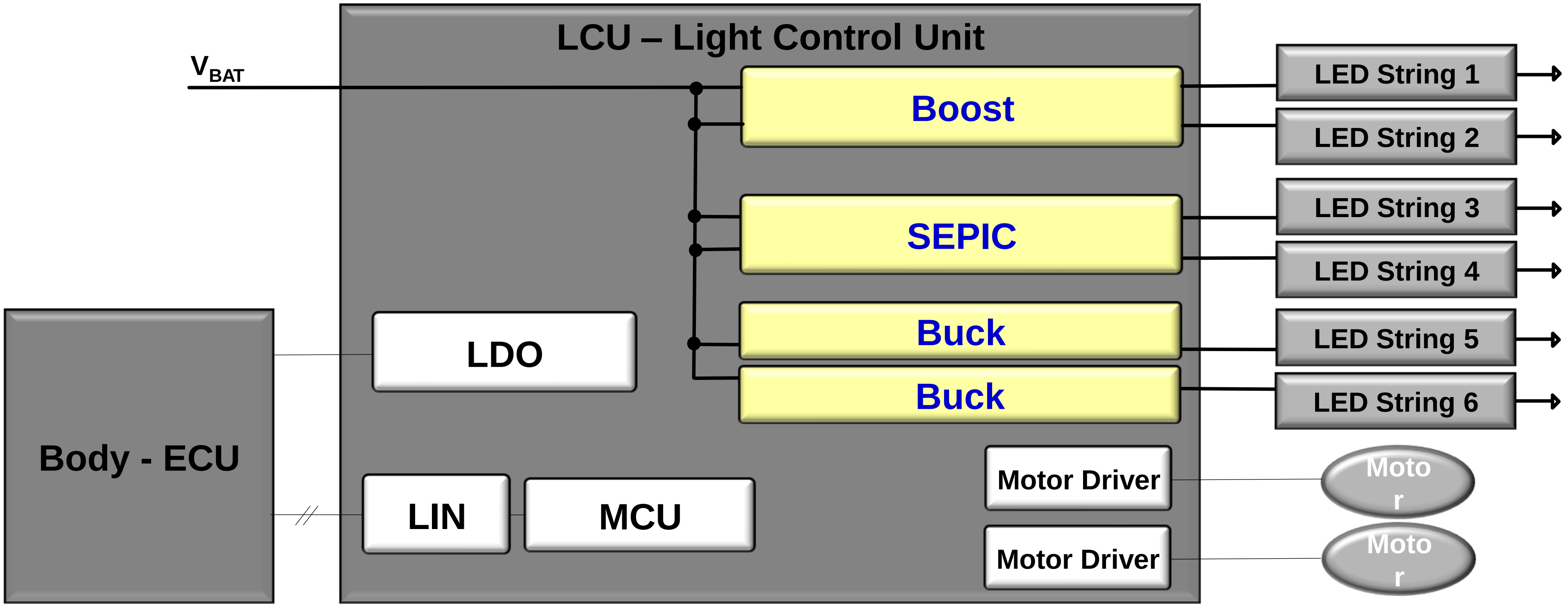
Applications

- **Head Light – Daytime Running Light, High Beam, Low Beam**
- **High Brightness LED Application**



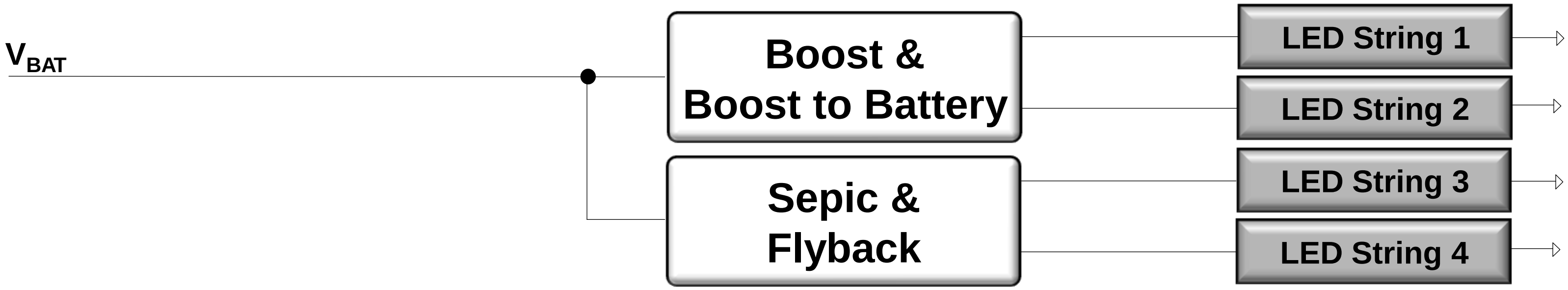
Head Light Control Unit
Single Stage Architecture

- Every LED String is directly driven out of the battery voltage
- Different Topologies depending on length of the LED String required
- Single Stage conversion offering highest Efficiency



Head Light Control Unit

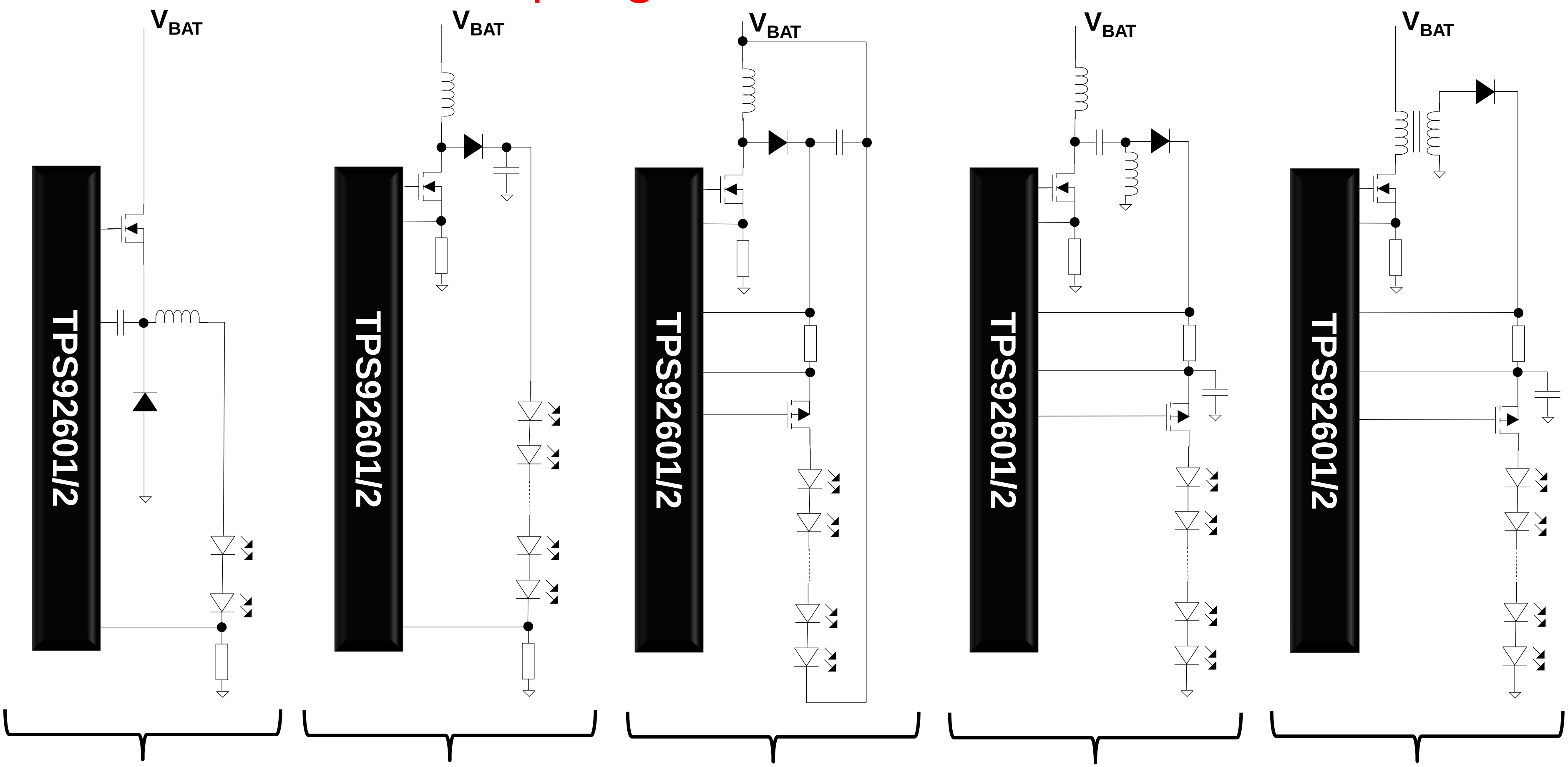
Single Stage Architecture Basics



Topology	Advantages	Disadvantages
Boost	+ single inductor only + efficiency ~ 90-95%	- $V_{BAT\_MAX} < V_{STRING}$ - conductive path from input to output
Boost to Battery	+ single inductor only + V_{BAT_MAX}<>V_{STRING} (Buck Boost)	- high side current sense required (limiting max LED string voltage to IC spec.) - conductive path from input to output
Sepic	+ no conductive path from input to output + V_{BAT_MAX}<>V_{STRING} (Buck Boost)	- 2 inductors required - current limitation (typ. 1-2A) - efficiency ~ 85 – 90%
Flyback	+ no conductive path from input to output + V_{BAT_MAX}<>V_{STRING} (Buck Boost)	- transformer required - lower efficiency than Boost

Head Light Control Unit

Generic LED Driver Topologies



Buck to Battery
(Buck)
$V_{BAT} > V_{STRING}$

Boost
$V_{BAT} < V_{STRING}$

Boost to Battery
(Buck–Boost)
$V_{BAT} <> V_{STRING}$

Sepic
$V_{BAT} <> V_{STRING}$

Flyback
$V_{BAT} <> V_{STRING}$

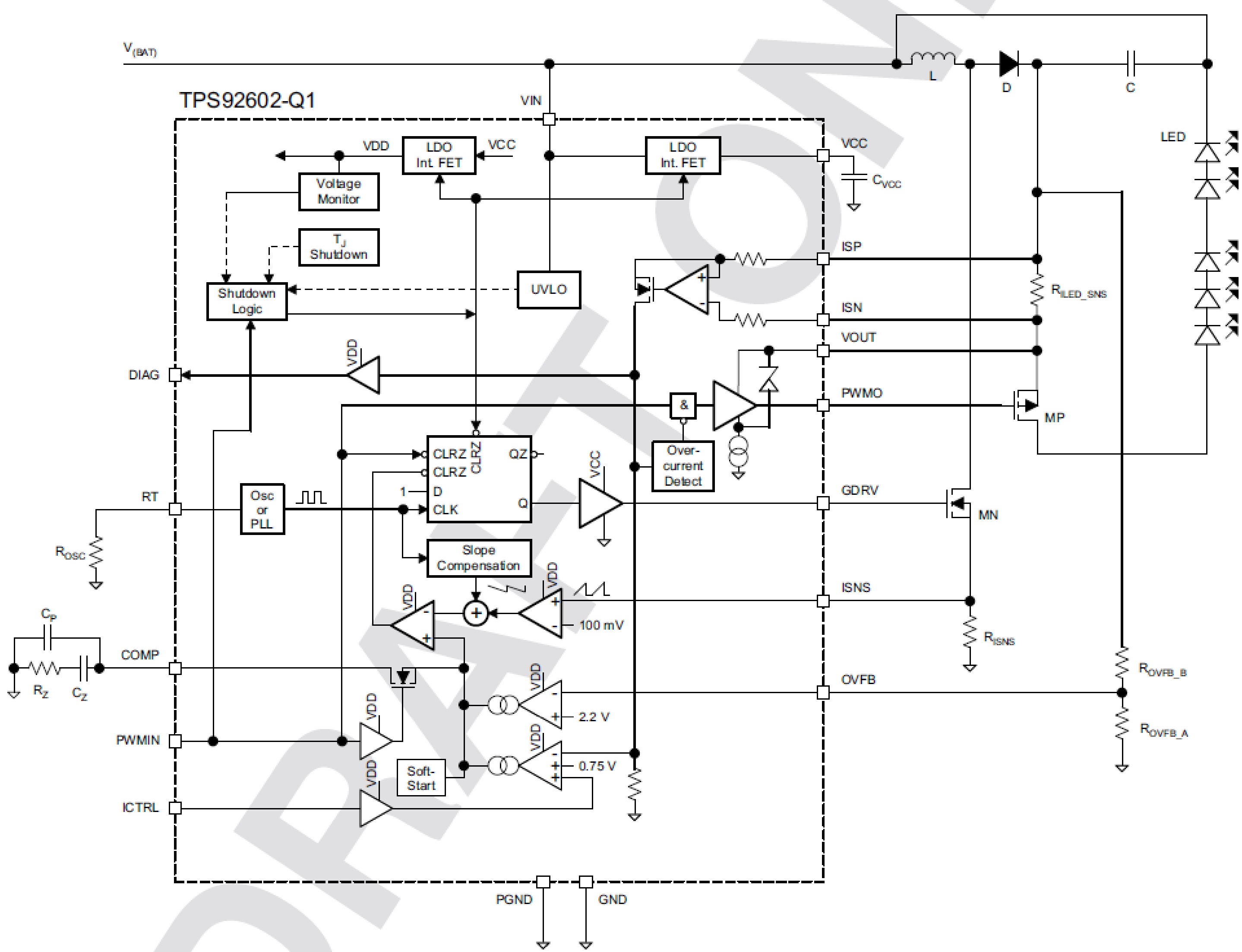
Legend

Production | Sampling | Development | Concept

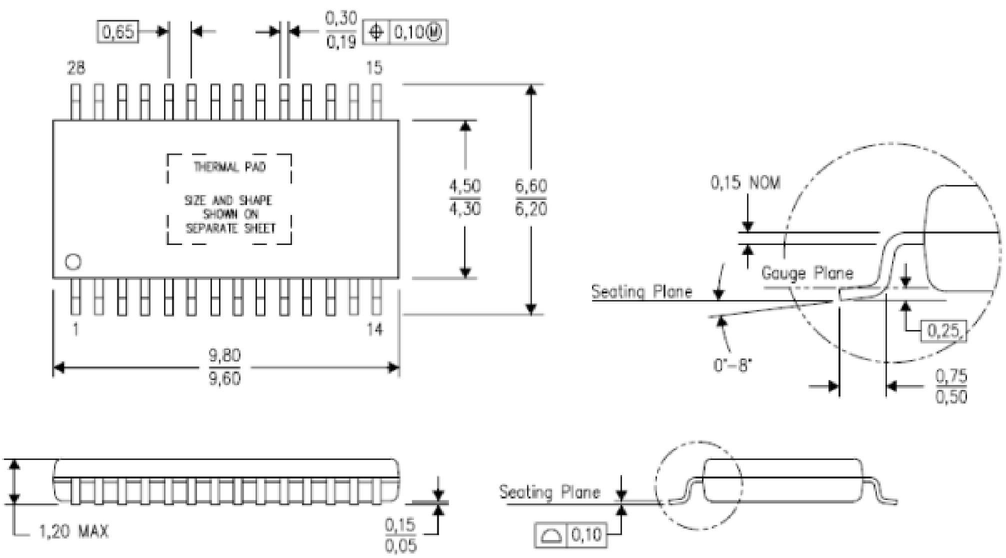
Value Proposition

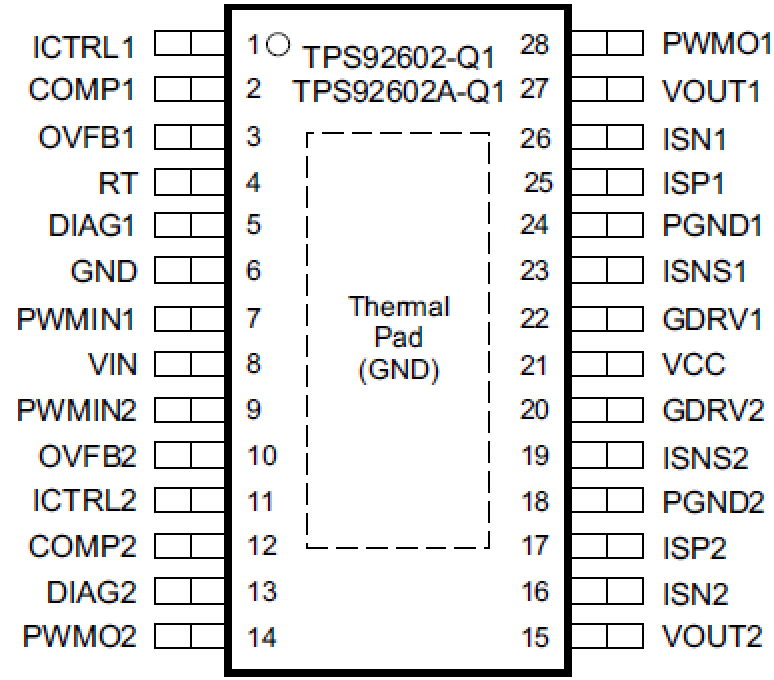
Features	Benefits
2 channel independent switching LED driver	Save PCB space and more cost effective
Support all kinds of topology -- Buck, Boost, Buck-Boost, SEPIC and Flyback	Offer design flexibility for customer to meet differenet requirements
Linear Analog Dimming with high side current sense	Saving PCB wire for low complexity, low cost and low risk in system design
Linear PWM dimming through high side PMOS-FET	Easy for system design and can protect the device and LED when Output short circuit and Over current happen
Dedicated DIAG pin	Feedback short and open status, and also measure LED current during normal condition
Smoothly switching between Constant Current and Constant Voltage when output LED Open	Protect device and LED when LED open or short to battery, also auto recover when the fault is removed

Functional Block Diagram



Package and Pin Assignment





Thank you.