TI LED Power and Control

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LED and TI Overview

LED Basics & Challenges

TI DC/DC LED Driver Solutions

Examples of SSL Lighting Today

- Large Panel RGB Displays
- Streetlights
- LCD TV Backlight
- Portable LCD Backlight
- Architectural Lighting
- Store Display Lighting
- Security Lighting
- Luminaires for General Lighting
- Stop Lights
- Rail Road Lighting
- Neon Light Replacements
- Flashlights

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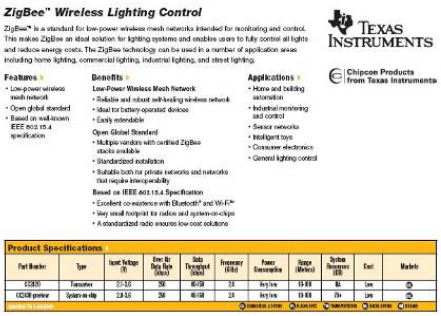
Multiple Lighting Technologies

Market	Equipments	Application
Automotive	Cluster	backlight toggle control
	Exterior Lighting	light source
	Interior Lighting	light source
Computer	Notebook	backlight lcd bias
Consumer	DLP	light source
	plasma	backlight
	projector	light source
	LCD TV	backlight
General	Architectural	light source
	Decorative	light source
	Industrial	light source
	Interior/Exterior Specialty Lighting	light source
Industrial	flashlights	light source
	Amusement	toggle control
Mobile Com	handset	backlight flash lcd bias
	MP3	backlight lcd bias
	PDA	backlight lcd bias
	PMP	backlight lcd bias
Medical / Industrial	LCD monitors	backlight lcd bias
Sinage	LED signs - high	color control
	LED signs - low	toggle control
	LED signs - med	color control

Portfolio strength in...

- **Linear Regulators**
- **Buck Converters**
- **Boost Converters**
- **Controllers**
- **RGB Matrix Drivers**
- **Low Power Wireless**
- **Low Power Microcontrollers**



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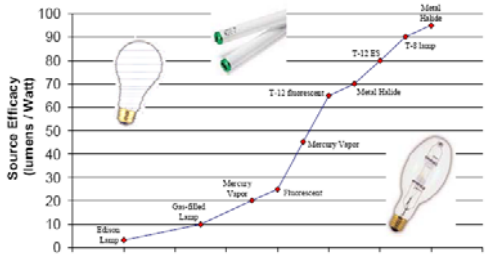
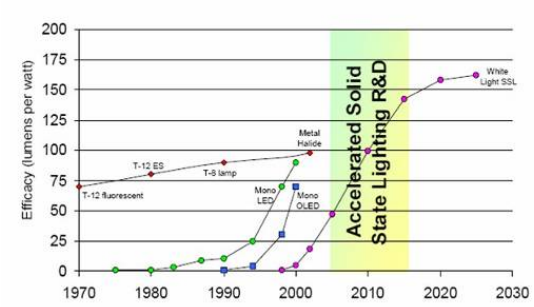
Efficacy Improvements Of White-Light Sources





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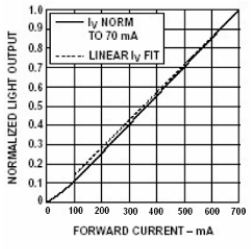
Lighting Challenges : Demystifying the LED

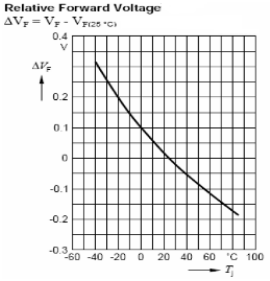
- ✓ Luminaires are the light fixtures where the LEDs reside for general lighting applications
- ✓ LED efficacy is defined by lumens/watt
- ✓ Color quality is the dominating factor in LED selection and is defined by color temperature, measured in degrees Kelvin.
- ✓ LEDs can appear as more efficient light sources than other conventional technologies because the light emitted is much more directional than conventional light sources which emit in all directions, LEDs focus light to where it is needed.
- ✓ Light output decreases as a function of temperature also light intensity decreases over time; an important aspect for any system design is to determine how much degradation will be permitted; 80% output is accepted as non detectable.
- ✓ White LEDs are normally blue but an added phosphor layer reacts with the small UV component of blue to create white.

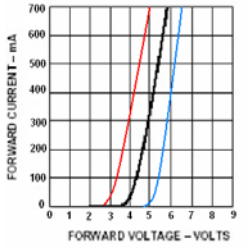
Lighting Challenges : Demystifying the LED

- ✓ Another method to produce white light is by mixing RGB diodes equally in proportion; you may often see two green LEDs with a single Red and Blue because green output does not match the lumen output of the two other colors.
- ✓ Light intensity is primarily controlled by current.
- ✓ Color temperature can change by both temperature and by the linear reduction of current, thus PWM dimming is the desired control method.
- ✓ Power dissipation is calculated from the product of current I x Vf (forward Voltage) or in many cases I x Vf x D… where D is the duty cycle
- ✓ Expected life is a function of operating junction temperature and follows the same rule as other semiconductors; for every 10oC rise in temp, expected life is ½ the max life.
- ✓ Thermal management is a main factor in any luminary design, Main value prop for LED lighting is the possible extended life, requires less often replacement compared to other light sources but poor thermal design will quickly kill this value.

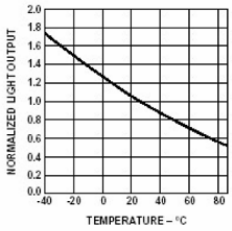
Variables Affecting Driver Design







Typical Forward Current versus Forward Voltage (Linear Scale).



Typical Luminous Flux versus Temperature (Linear Scale).

Vf between LEDs can vary widely - must use max spread to determine worst case Vf to determine min headroom.

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TEXAS INSTRUMENTS

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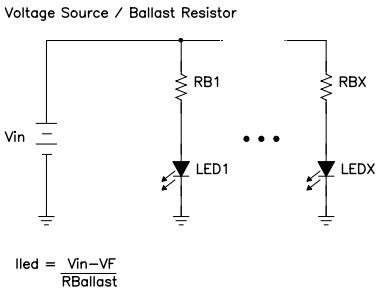
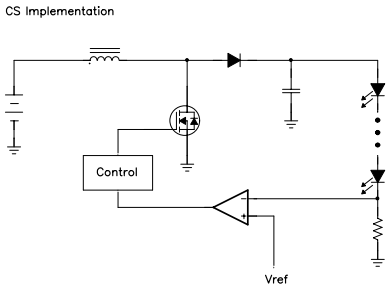
Setting LED Current





- Voltage Controlled
  - Cheap
  - Simple
  - Extremely Poor regulation
- Current Controlled
  - More expensive
  - Excellent regulation

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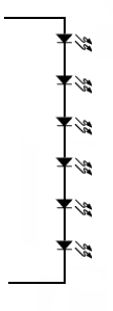
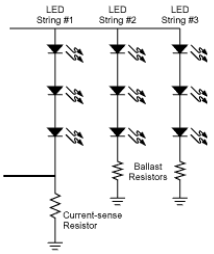
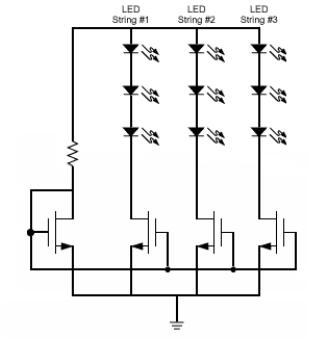
Voltage source – Non regulated current. Small changes in either the input voltage or LED forward voltage result in poor current regulation. Battery voltage varies significantly. LED Vf varies between LEDs and with temperature. Regulation can be as poor as +/- 25%.

Current source – Active current feedback. Compensates for all variations and provides very tight tolerances.

Multiple LED Configurations







◆ Easiest to implement and Control	◆ Low Cost	◆ Best Parallel Control
◆ Limited by converter topology or possibly Safety voltage limitations	◆ Poor Regulation	◆ Most Expensive
◆ Current matching	◆ Lossy w/o Op Amp amplifier	◆ Need matching MOSFETs
		◆ Linear (lossy)

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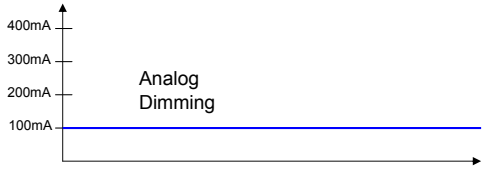
Analog vs PWM Dimming

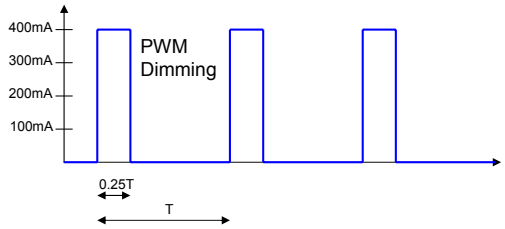
Analog

- Changing the LED's DC current changes LED intensity
- i.e.,25% brightness by running a 400mA LED at 100mA
- Implemented with digital programming of IC or with an external voltage



PWM

- Changing duty cycle of applied current
- i.e., 25% brightness by running 400mA for only 25% of the time.
- PWM frequency should be greater than response time of human eye (approx 60Hz)
- Implemented with PWM of IC enable or external voltage



Solutions to Challenges

TI DC to Constant Current LED Driver Examples

Low Power Or Single HB LED

- TPS63000 Buck/Boost Driver
- TPS610x – Boost Driver
  - TPS6108x
  - TPS61040/1/2
  - TPS6105x
  - TPS6106x
  - TPS61158/9
  - TPS61200
- TPS62xx – Buck Drivers
  - TPS62050 800-mA 10V Vin
  - TPS62100 500-mA, 9V Vin

High Power

- TPS40K – DC Adjustable Current HB LED Driver
- TPS5430 – DC Integrated FET HB LED Driver
- TPS43000 – Multi-Topology High Frequency HB LED Driver
- UCC280x – 24Vin Boost HB LED Driver
- UCC3813 – Current Mode PWM for Simple Offline LED Driver

TPS63000

Family 96% Efficient Buck/Boost Driver

Features

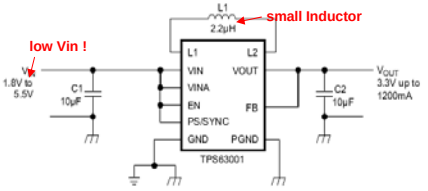
- Input Voltage: 1.8-V to 5.5V
- Output Voltage: 1.2V to 5.5V, 3.3V, 5.0V
- Output current Switch: 1.7A
  - up to 1200mA output current in Buck configuration @ 3.3V
  - up to 800mA output current in Boost configuration @ 3.3V
- Efficiency: 96% over wide Vin range (max)
- Package: 3x3 QFN
- Automatic Transition between Step Down and Boost Mode
- Device Quiescent Current less than 25-µA
- Power Save Mode for Improved Efficiency at Low Output Power
- Forced fixed Frequency Operation possible
- Load Disconnect During Shutdown
- Over-Temperature Protection

Benefits

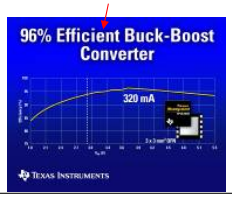
- Smallest solution size, requires only 2.2uH Inductor
- Supports input voltages as low as 1.8V (for 2-cell Alkaline)
- Highest efficiency over wide Input range

Applications

- All 2-Cell and 3-Cell Alkaline, NiCd or NiMH or Single-Cell Li Battery Powered LED Equipments



unique Efficiency performance



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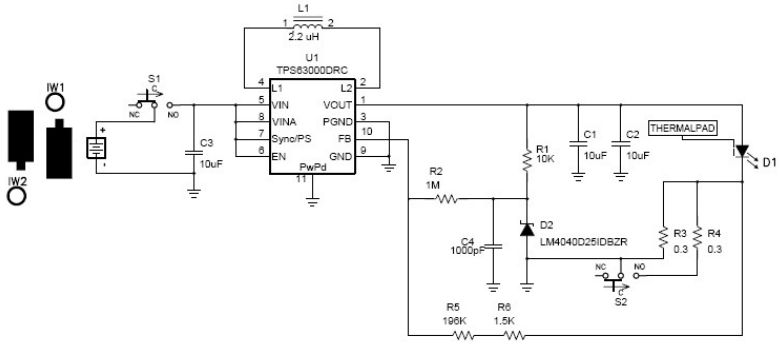
Battery Powered Buck-Boost LED driver



Actual design used by Cree for demonstration board

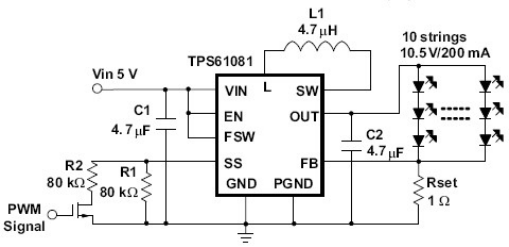
TPS61080/1
High V_{out} Boost Driver

Features
- Input Voltage: 2.5V to 6.0V
- Output Voltage: **up to 27V (**max)
- Switch current Limit:
  - 0.5A (TPS61080)
  - 1.3A (TPS61081)
- Efficiency: **85%** (max)
- 10 pin 3x3mm QFN package
- Input-to-output isolation ← **great for medical**
- Short circuit protection
- Overvoltage protection
- Thermal protection
- Adjustable Softstart
- Integrated power diode
- 600kHz or 1.2MHz fixed switching frequency

Applications
- LCD Bias supply
- **OLED** Bias Power Supply
- White **LED** backlight
- White LED flashlight

Benefits
- Smallest solution size
- Highest Efficiency
- Several Protections Circuits

30 WLEDs Driver in Media Factor Form Display



The differential feature of the device is high reliability. The device can protect itself and external components when there's short between any pins and between any pin to ground.

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Main difference to our existing TPS61045 or TPS6106x series is the much larger Power FET which enables higher output currents.

Second key feature is the build in Input-to-Output isolation which enables us to support also DINs within the Medical and Industrial world.

Great for mid sized medical OLED TFT bias

TPS61040/1

28-V Boost Driver in SOT-23

Features

- Output voltage up to **28V**
- 400/250-mA switch current limit (TPS61040/1)
- High Efficiency: **>85%**
  28-µA no-load quiescent current typ
- **SOT23-5** package, small inductors, low value capacitors & low overall component count
- Input voltage range 1.8V to 6.0V
- **TPS61040EVM-001**
- **TPS61040EVM-002 (White LED)**
- T_A -40 to 85°C

Benefits

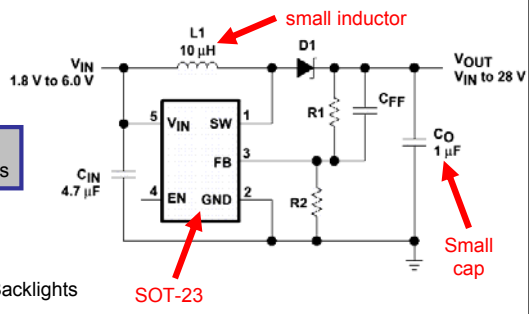
- Ideal for LCD bias and White LED Backlight applications
- Extends battery life
- Enables ultra-small solutions
- Suitable for: 2- & 3-cell alkaline + 1-cell Li-Ion

Why Use

Industry's highest efficiency, lowest quiescent current in SOT-23 for ultra-small implementations

Applications

- LCD Bias Supply, White-LED Supply for LCD Backlights



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SHORT-FORM DESCRIPTION

The TPS6104x series of low-power DC/DC boost converters features an output voltage up to 28V from an input voltage in the range of 1.8V to 6.0V. Both TPS61040 (400-mA switch limit) and TPS61041 (250-mA switch limit) feature an efficiency greater than 85%, low 28-uA quiescent current, space-saving SOT-23 package and are ideal for LCD bias and white LED backlight applications.

WHY WAS THIS PRODUCT DEVELOPED?

The TPS61040/1 marks TI's entry point into the huge and fast-growing market for LCD and white LED backlight supplies. Up to now TI didn't offer a device that could step up a voltage to this level. The TPS61040/1 fills a gap in the portfolio and was originally developed to take share from the pin-compatible LT1615. More advanced TPS6104x devices will follow.

OTHER SOLUTIONS & HOW TO SELL

A couple of LTC and Maxim devices (**LT1615/1613/1930, MAX1605** all ~$1.70/1ku) are already existing in the market for these applications. You will also occasionally encounter the Microsemi **LX1992** controller (external FET), Toko **TK11850** or On Semi **NCP1403**. However, the TPS61040/1 features a very competitive combination of highest efficiency and low quiescent current out of a SOT-23 package, coupled with the need for only very small inductors and capacitors which enables the most cost-efficient and smallest implementations. Flexibility for component selection is very high. For lower power applications TPS61041 works with smaller inductor values and a 100-nF cap. Competition may require >1µF.

To compete, win the socket first or displace existing solutions meeting the competition's solution price with the aggressive TPS6104x pricing (100ku @ ~ $0.70). Also offer the EVM to facilitate the design.

FACTORY Contacts

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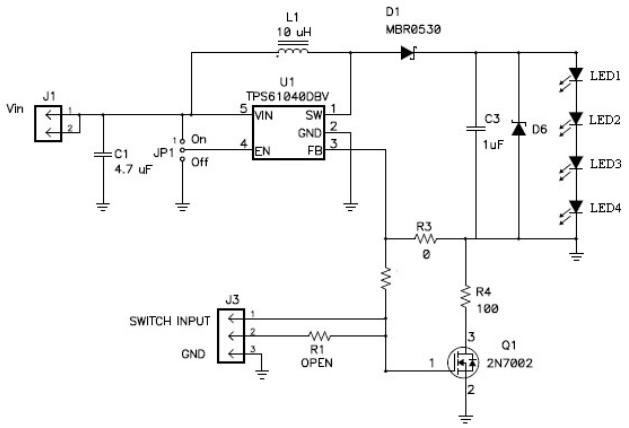
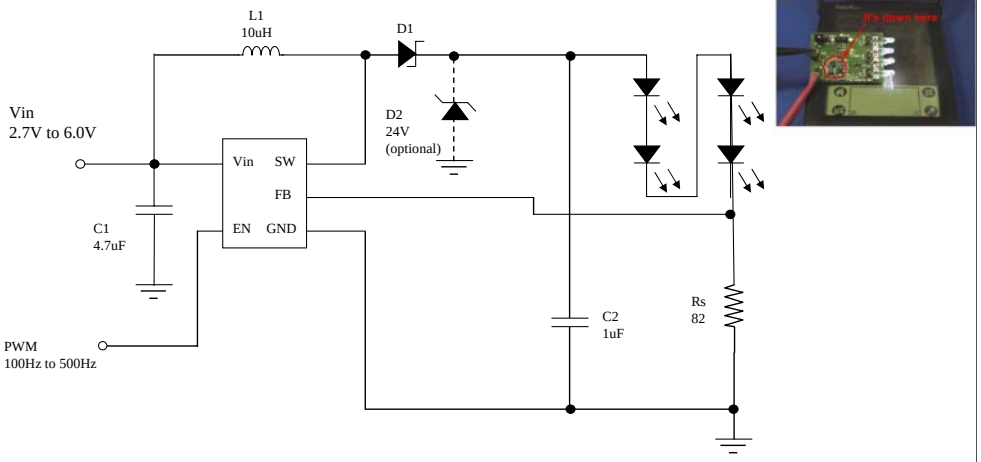
TPS61040 28-V Boost LED Driver

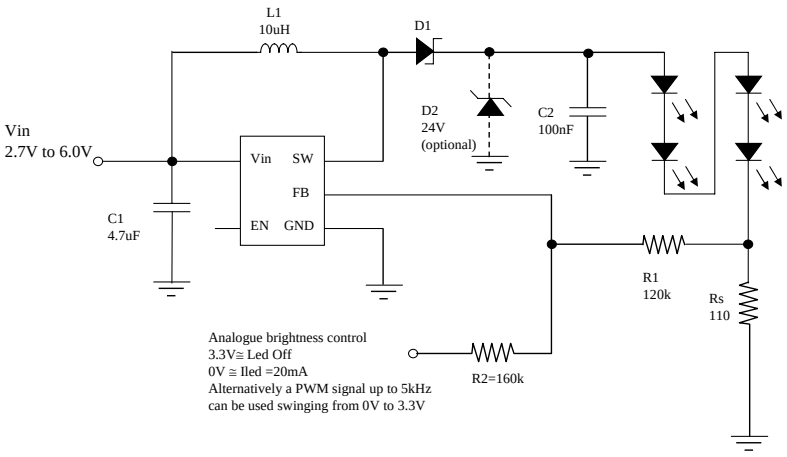


White LED backlight supply
PWM brightness control at EN



Efficiency@Vin=3.0V and 15mA = 86%

White LED backlight supply
analogue / PWM brightness control at FB



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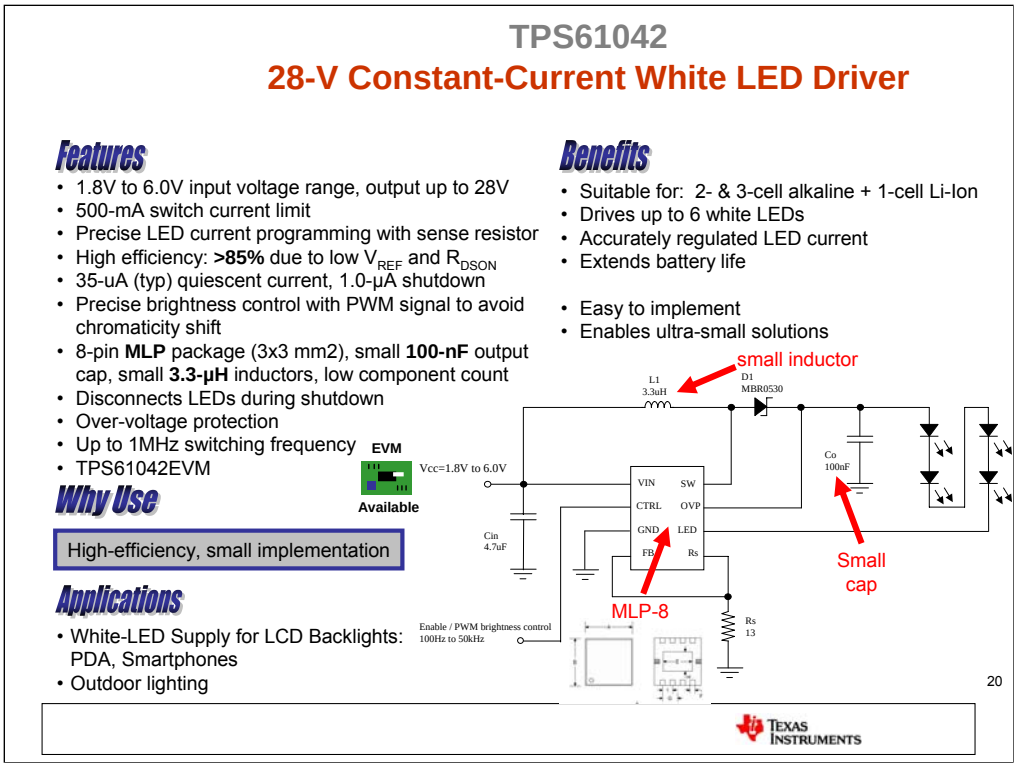

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TPS61058/59:
White LED Flashlight Boost Converter

Features

- Input Voltage: 2.7V to 5.5V
- Output Voltage: 2.5V to 5.5V
- Output Current:
  - 1100mA Switch Current Limit (TPS61058)
  - 500mA LED Current from 3.3-V Input
  - 1500mA Switch Current Limit (TPS61059)
  - 800mA LED Current From 3.3-V Input
- Efficiency: 80% (max)
- Package: 3x3 QFN-10
- Fixed Frequency 650kHz (typ) Operation
- LED Disconnect During Shutdown
- Open/Shorted LED Protection
- Low EMI-Converter (Integrated Anti-ringing Switch)
- Internal Soft-Start
- Over-temperature Protection
- Low Shutdown Current: 100nA (typ)

Benefits

- Minimizing external component count with total solution size of ~80mm^2

Applications

* Torch/Camera Flashlight
* White LED Backlight
* Generic Lighting Applications

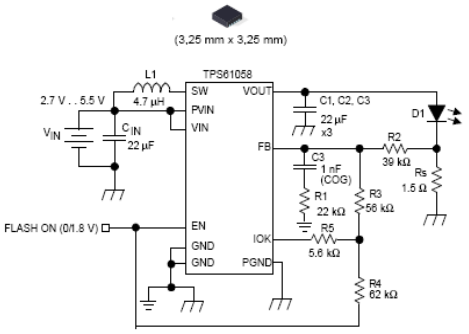
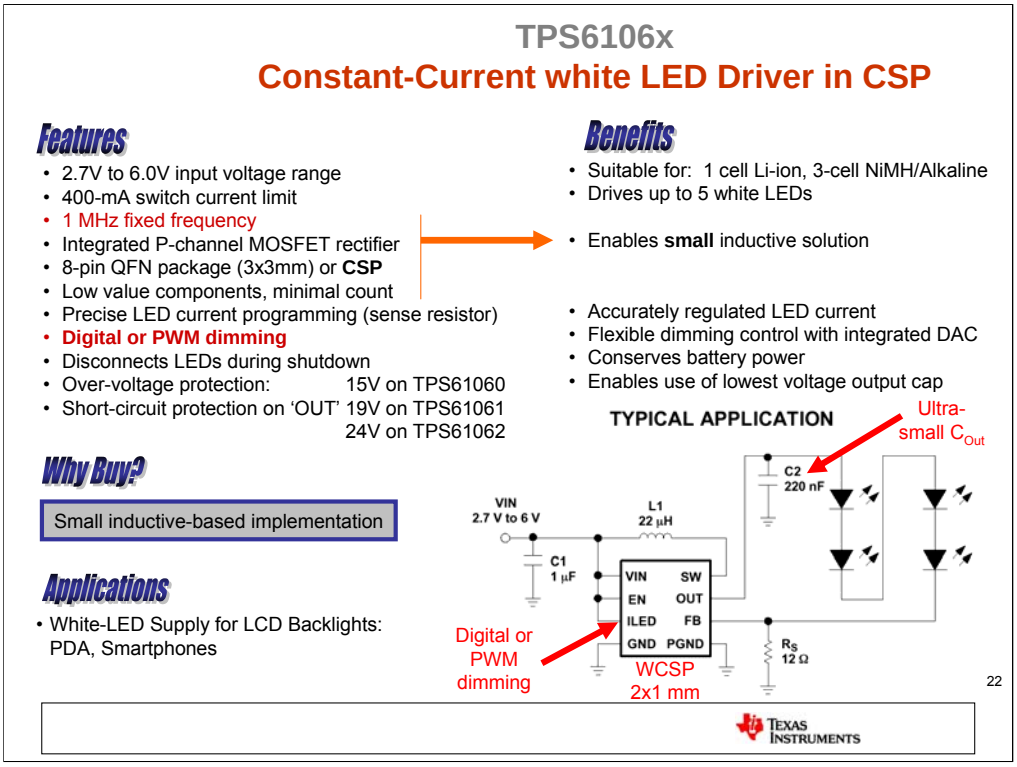


Figure 1. 500 mA Flashlight Application



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TPS6115x
Dual Output – single Inductor - LED Driver

Features

- Input Voltage: 3.0V to 6.0V
- Output Voltage: up to 27V each (max)
- Switch current Limit: 0.7A (max)
- Efficiency: 83% (max)
- Package: 3x3 QFN-10

- 2 Individual programmable, regulated current Outputs
- build in Power Diode & Soft-start
- Input to Output isolation
- Overvoltage & Short circuit protection
- Built in 1.2MHz fixed switching frequency

Benefits

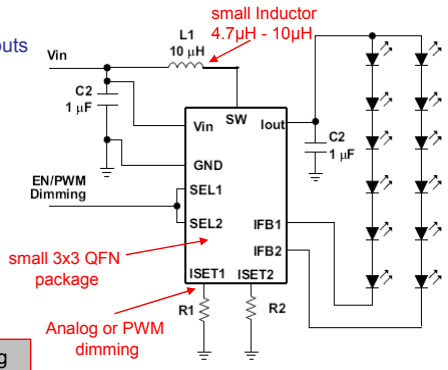
- Controls 2 strings with only 1 Inductor
- both strings can be on at the same time
- up to 30kHz dimming frequency

Why buy

- Best in class backlight driver performance, dimming capabilities and total solutions size

Applications

- LED driver for up to:
  - 12 LED (4.0V forward voltage)
  - 14 LED (3.5V forward voltage)



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TPS61200
0.3V Input Voltage Synchronous Boost Driver

Features

- Input voltage: 0.3V to 5.5V
- Startup into full load at 0.5V input voltage
- 1.8V to 5.5V output voltage
- Switch current limit: 1.5A (max)
- More than 90% efficiency at:
  - 600mA output current at 3.3V (V_{IN} ≥ 1.2V)
  - 600mA output current at 5V (V_{IN} ≥ 3.3V)
- Quiescent current: < 55µA
- Package: 3x3 QFN

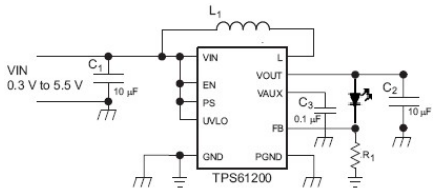
Applications

- 1-/2-/3-cell alkaline, NiCd or NiMH battery or 1-cell Li battery powered lamps
- Single-solar cell and micro-fuel cell powered lamps
- Portable solar charger

Special Features

- Integrated 'DownMode' enables continues operation during V_{IN} > V_{OUT} conditions
- Automatic transition between Boost mode and Down Conversion mode
- Programmable undervoltage lockout threshold, down to 0.0V possible
- Load disconnect during shutdown

Perfect for Single Cell Alkaline Torch



TPS62050 Family:
800-mA, 10V V_{in}, Step-Down Driver

Features

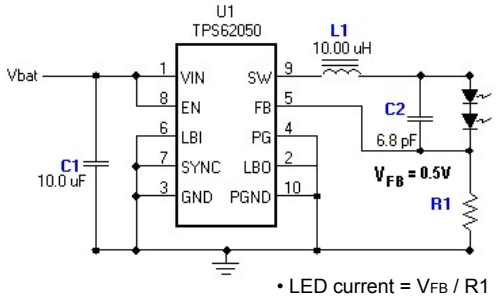
- 2.7V to **10V** ($11V_{max}$) input voltage range
- Up to **800-mA** output current, up to **95%** efficiency
- **12-uA** (typ) quiescent current, 2-µA shutdown
- PFM power-save mode for light loads
- 850-kHz (typ) operation, synchronizable to external clock up to 1.2MHz
- Forced-PWM mode available
- Power Good and **low-battery detect**
- Soft-start limits in-rush current
- MSOP-10 package

Why Buy?

Industry's best combo of high efficiency, low power and output current

Benefits

- Suitable for 3- to 6-cell alkaline or 1- to 2-cell Li-Ion as well as 9-V wall adapter applications
- Conserve battery capacity, limit heat dissipation small inductors – **10µH** reduces noise



- LED current = V_{FB} / R1

1ku / $1.85

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TEXAS INSTRUMENTS

SHORT FORM DESCRIPTION

The TPS6205x series of **95% efficient**, low quiescent current (**12µA**) synchronous step-down dc/dc converters delivers up to **800mA** of output current from a 3x5mm2 MSOP-10 package and generates output voltages in the range of **0.7V to 6V**.

The wide operating input voltage range of **2.7V to 10V** makes the device very versatile and very low quiescent current along with high conversion efficiency are ideal for 1- & 2-cell Li-Ion battery or 3- to 6-cell NiMH / NiCd / Alkaline applications.

WHY BOTHER / ADVANTAGES OVER COMPETITION

The TPS6205x fills a gap in the TI portfolio and offers **three key improvements** over the last generation part TPS6200x:

1.) higher input voltage range: Allows the use in 2-cell Li-Ion and 9V wall adapter applications.

2.) higher output current (800 vs 600mA).

3.) lower quiescent current (12 vs 50µA) for longer battery stand-by time.

Various competitive solutions from LTC, Sipex, Torex, Vishay and Maxim offer similar performance characteristics at widely varying prices. The key strength of the TPS6205x is the combined performance of input voltage range, output current and low quiescent current coupled with a very attractive price.

All spins of the TPS6205x have a suggested resale price of $1.74 in quantities of 1000. 100ku direct for $1.01. For evaluation purposes evaluation modules TPS6205xEVM will be available by Q103 via the PIC, Distributor or Sample Room. Resale price is $50.

TPS62100 Family
500mA, 9V Vin Step-Down DC/CC

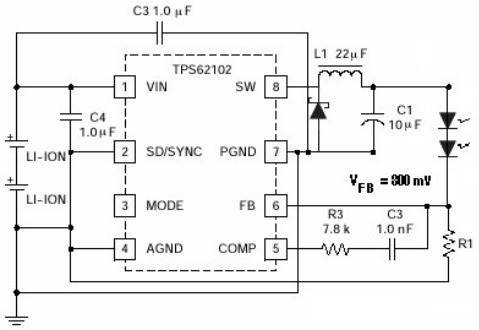
Features

- **2.5V to 9V** Input Voltage Range
- **500mA** Output Current
- Switching frequency: 300kHz, 600kHz, 1MHz, 2MHz
- 100% Duty cycle for lowest dropout
- PWM/PFM operation for highest efficiency over wide load current ranges
- External Synchronization
- 8 pin SOIC

Benefits

- Suitable for 3- to 6-cell alkaline or 1- to 2-cell Li-Ion as well as 9-V wall adapter applications
- Conserve battery capacity, limit heat dissipation small inductors
- Multiple frequency options available for choice in size or efficiency constraints

	TPS62100	TPS62101	TPS62102	TPS62103
Switching Frequency	600 kHz	1000 kHz	2000 kHz	2500 kHz



• LED current = V_{FB} / R1

TPS40200

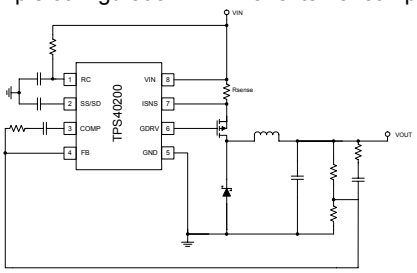
Wide Input, Low Pin Count Driver

Features

- 4.5V to 52V operation
- Voltage Mode Control with Feed Forward Compensation
- 700mV Voltage Reference - 1% accuracy
- Internal Under-Voltage Lockout
- Programmable Frequency (35kHz-500 kHz)
- Programmable Overcurrent Protection
- Frequency Synchronization
- Closed Loop Soft Start
- Integrated Driver
- Package - 8 pin SOIC

Benefits

- Wide input range for use in many applications
- Voltage feed forward – great line regulation, fast transient response
- Programmable features allows flexible design; frequency, overcurrent protection, under voltage lockout
- Softstart provides smooth, well controlled power up
- Simple configuration- minimal external components



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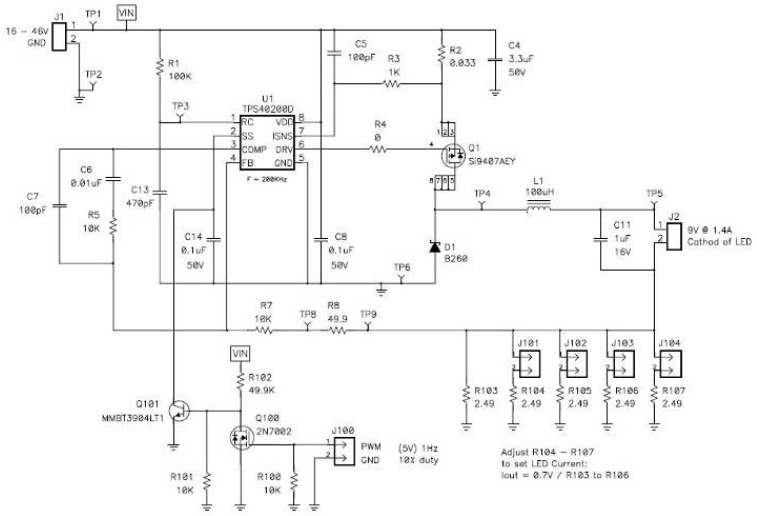
Adjustable Current HB LED Driver



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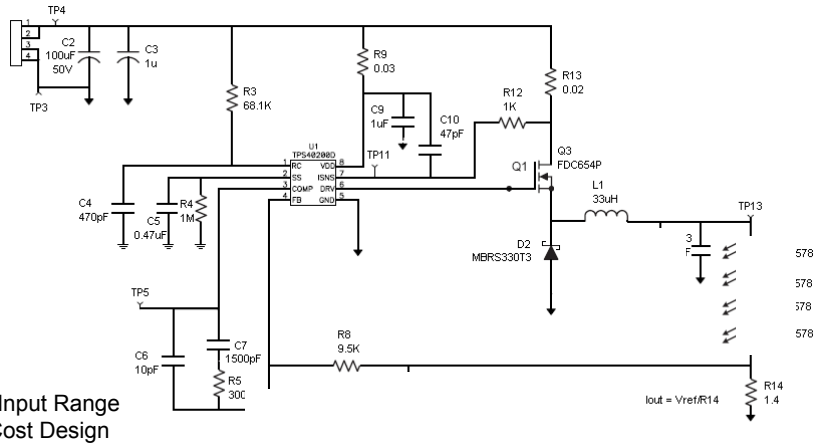
Driving High Current LEDs (Buck Converter)

Vin= 4.5V to 52V



- Wide Input Range
- Low Cost Design
- Few Components
- Highly Flexible
- 90% Max Duty Cycle
- Simple Low Cost Solution

LED Current = 500mA
LED Vf = 5V

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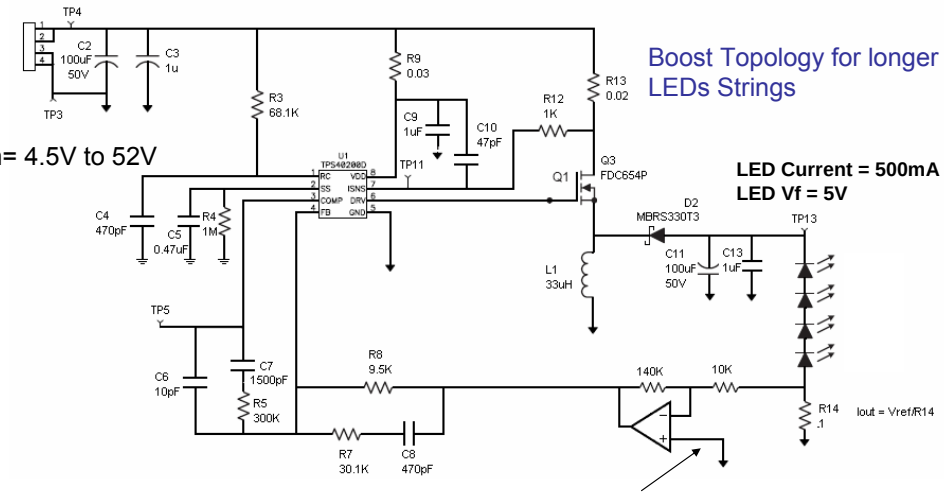
Driving High Current LEDs with the TPS40200



Vin= 4.5V to 52V

Boost Topology for longer LEDs Strings

LED Current = 500mA
LED Vf = 5V

PWM Dimming Capabilities

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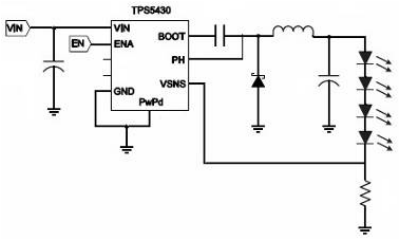
TPS5430 - 5.5V to 36V Input, 3-A Step Down LED Driver

Features

- Integrated 110mΩ N-channel MOSFET
- Fixed 500kHz Switching Frequency
- Output Voltage to 1.23V with 2% accuracy
- Internal Slow Start Circuit
- Internal Compensation
- Enable Pin
- Current limit & Thermal Shutdown
- Only 17uA Shutdown Quiescent Current
- -40°C~125°C Operating Junction Temp.
- Thermally Enhanced 8 pin HSOIC
- SWIFT™ Software Tool

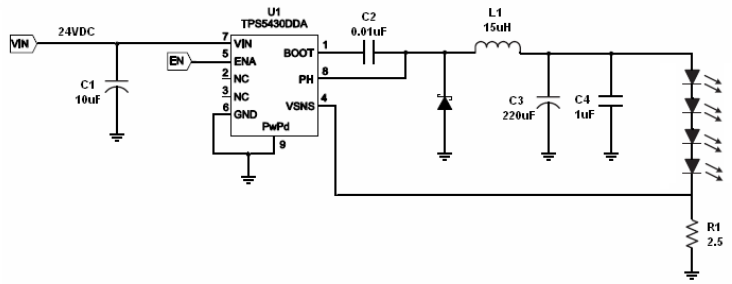
Benefits

- High Efficiency Up to 95%
- Small Output Inductor & Capacitor
- High Performance
- Limits Start-up Inrush Current
- Reduced External Components
- Easy On/Off Control
- Self-Protected from Fault Conditions
- Low Power Consumption when Switched Off
- Reliable & Robust at Extreme Temperatures
- Small with Good Thermal Performance
- Quick & Easy Design www.ti.com/swift



TEXAS INSTRUMENTS

Driving High Current LEDs with the TPS5430



- Wide Input Voltage Range: 5.5 V to 36 V
- Max 3A drive current
- Buck Converter Output up to 87% Vin
- Internally Compensated, eliminates components
- High Efficiency with Integrated 110mOhm MOSFET

TPS43000

Multi-Topology High Frequency PWM Controller

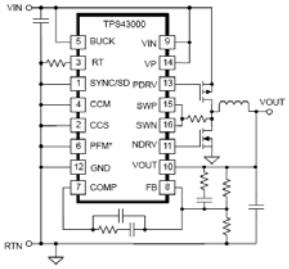
Features

- 2 MHz Switching Frequency
- Voltage Mode Control
- High Efficiency Synchronous Rectification Drivers
- Fully functional from 1.8V through 9V
- Works with Buck, Boost SEPIC and Flyback Topologies
- Fixed Frequency Operation or Pulse Frequency Modulation (PFM) Mode
- Built-In Soft Start
- User Programmable Discontinuous or Continuous Conduction Modes

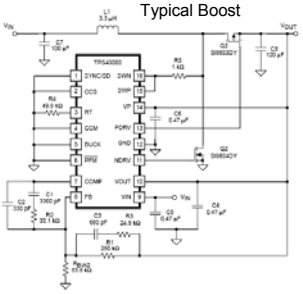
Applications

- 2 to 4 Cell Alkaline or Nickel, 2 Cell Lithium Lamps
- High current boost from 5V wall adapter

Typical Sync Buck

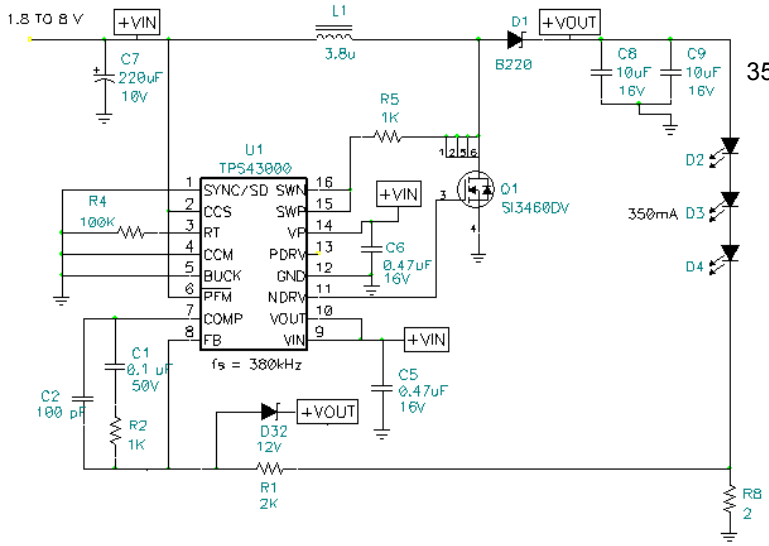


Typical Boost



TEXAS INSTRUMENTS

TPS43000 LED Driver



Vin=1.8V to 8V
350mA LED current

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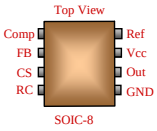
UCC280x - Current Mode PWM Controllers

Features:

- 100-µA Typical Starting Supply Current
- 500-µA Typical Operating Supply Current
- Operation to 1 MHz
- Internal Soft Start
- Internal Fault Soft Start
- Internal Leading-Edge Blanking of the Current Sense Signal
- 70-ns Typical Response from Current-Sense to Gate Drive Output
- 1.5% Tolerance Voltage Reference
- Same Pinout as UC3842 and UC3842A



Part Number	Max Duty Cycle	Ref. Voltage	Turn-On Threshold	Turn-Off Threshold
UCC2800	100%	5V	7.2V	6.9V
UCC2801	50%	5V	9.4V	7.4V
UCC2802	100%	5V	12.5V	8.3V
UCC2803	100%	4V	4.1V	3.6V
UCC2804	50%	5V	12.5	8.3V
UCC2805	50%	4V	4.1V	3.6V

PWM controllers with Peak Current Mode or Average Current control methodology use a dual-loop control circuit to adjust the regulating pulse width in response to load changes. Current Mode controllers provide a fast transient response with built-in current limiting.

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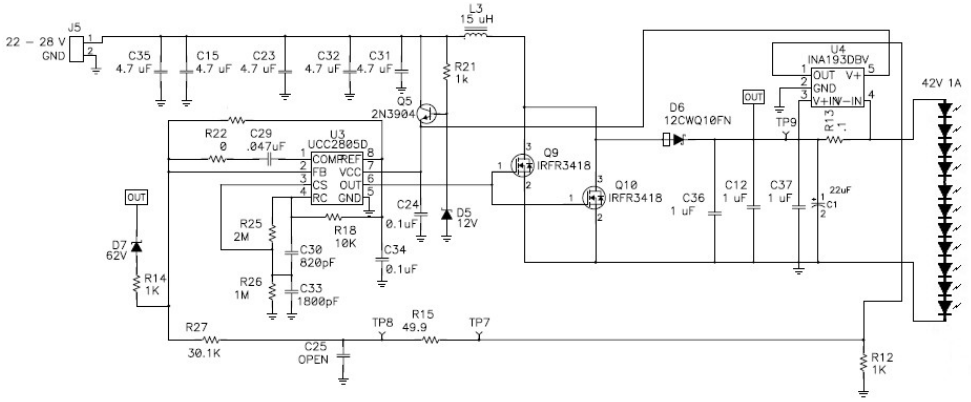
24Vin Boost LED Driver



UCC3813 Current Mode Pulse Width Modulator

- 100 µA typical starting supply current
- 500 µA typical operating supply current
- Operation to 1 MHz
- Internal soft start
- Internal fault soft start
- Pricing: $ 0.64 @ 50K
- Internal leading-edge blanking of the current sense signal
- 1A totem-pole output
- 70 ns typical response from current-sense to gate drive output
- 1.5% tolerance voltage reference
- Same pinout as UC3842 and UC3842A

Part Number	Maximum Duty Cycle	Reference Voltage	Turn-On Threshold	Turn-Off Threshold
UCC3813-0	100%	5V	7.2V	6.9V
UCC3813-1	50%	5V	9.4V	7.4V
UCC3813-2	100%	5V	12.5V	8.3V
UCC3813-3	100%	4V	4.1V	3.6V
UCC3813-4	50%	5V	12.5V	8.3V
UCC3813-5	50%	4V	4.1V	3.6V

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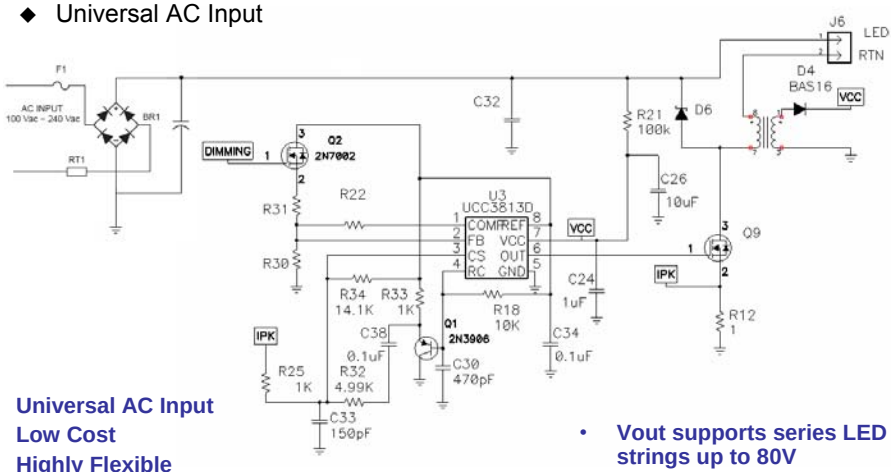
Here's our most popular PWM for both AC/DC and DC/DC converter applications. With it's numerous internal functions, designers appreciate the few external components required to complete the control circuit design. These parts get the job done cost effectively and use only 8 pins.

Off-Line LED Driver

- Universal AC Input



- **Universal AC Input**
- **Low Cost**
- **Highly Flexible**
- **PWM Dimming**

- **Vout supports series LED strings up to 80V**
- **ILED up to 650mA**

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Key LED System Questions

- LED Vf
- LED Current
- Number of LEDs
- LED configuration (series, parallel, series & parallel)
- Input voltage range
- Current Matching Requirements
- Efficiency Requirement
- Application (backlight, active display)
- Dimming (Y/N; Analog or PWM)

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LED Vf

Maximum output voltage

Solution Topology (boost, buck)

LED Current

Topology (switcher, charge pump, current mirror)

LED configuration (series, parallel, series & parallel)

Topology

Input voltage range

Topology (buck, boost)

Current Matching Requirements

Topology (series, parallel)

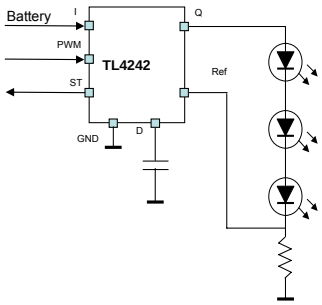
Efficiency Requirement

THANK YOU

TL4242 Constant Current LED driver

Features

- Adjustable constant current up to 500 mA (±5%)
- Wide input voltage range up to 42 V
- Open load detection
- Overtemperature protection
- Short circuit proof
- Reverse polarity proof
- Wide temperature range: -40 °C to 150 °C



Benefits

- Supply voltage independent constant current / brightness
- PWM capability for dimming
- No external power resistor required
- Diagnostic capability

Applications

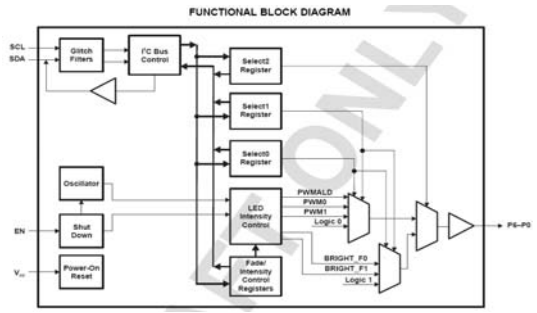
- LED illumination and intensity control
- Exterior: DRLs, fog light, turn lamp, headlamp, …
- Interior: vanity light, map light, courtesy light, …

In Development

TCA6507 – I²C LED Drivers (7-bit)

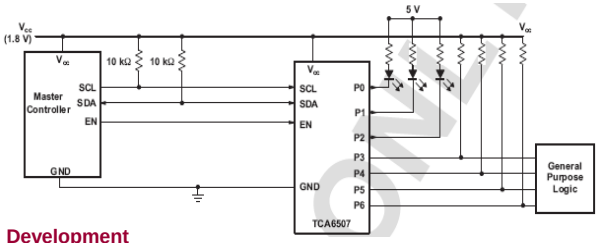
Features

- **7 LED drivers which are monitored through I²C protocol**
- **Can be configured as 2 banks of LEDs**
- **Each bank has Independent Control for Blink Rate and Intensity**
- **Vcc range of 1.65V to 3.3V on I²C side and control logic**
- **Output voltage is 0 to 5.5V**
- **Shutdown feature for additional power savings**
- **Enable input can reset the device to the default state without de-powering the device**
- **400kHz Clock Frequency**
- **Open-drain outputs; 25mA drive**



Benefits

- **Outputs not used as LED Drivers can be used as regular general purpose outputs**
- **Improves on existing I²C LED drivers in the industry**
  - Lower Vcc range to interface with next generation processors
  - Lower power consumption for battery-powered portable applications



In Development

TEXAS INSTRUMENTS

LED DRIVERS

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Digital Video Displays

Billboards

Alphanumeric Displays

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NOTES:

TI LED Drivers are used in end equipment applications ranging from low end alphanumeric displays (TLC5921) to high-end full motion video displays (TLC5940).

LED Driver – Large Panel Display