LED Drivers for High-Brightness Lighting

Solutions Guide

national.com/LED

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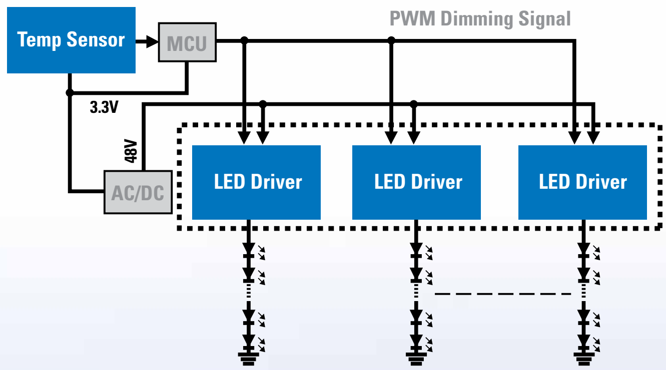
PowerWise®



National Semiconductor

Energy-Efficient LED Driver Designs

national.com/LED

For 50 years, National has been known for its reliable, energy-efficient power management products. The company continues to bring this knowledge, experience, and manufacturing capability to help customers create better lighting designs. National's LED drivers incorporate the intelligence that systems need to deliver high-performance, reliable, and robust LED lighting solutions to the market.

National Semiconductor's broad portfolio of PowerWise® energy-efficient power management ICs provide constant current for driving both low-power and high-brightness LEDs, enabling color and brightness matching over a wide temperature range. These LED drivers enable greater energy efficiency and flexibility in lighting designs. Driving numerous LEDs in one string, they provide greater than 90 percent efficiency and accurate current regulation with less power and heat dissipation.

Solving Customer Design Challenges

To enable customers to build differentiated products more quickly, National's easy-to-use solutions address a number of lighting design challenges through features such as:

- Dynamic headroom control to maximize system efficiency
- Multiple outputs maximize LED strings per driver and reduce system solution size, cost, and complexity
- Thermal foldback ensures LEDs operate reliably over varying temperature conditions for a robust solution that doesn't require complex external temperature sensing circuitry
- Patent-pending architectures enable state-of-the-art TRIAC/ phase dimming compatibility in LED retrofit lamps and new installation fixtures for a seamless transition to LED lighting technology
- Analog and Pulse-Width Modulation (PWM) dimming capabilities for design flexibility
- Small driver solutions for space-constrained applications
- Tools such as WEBENCH® LED Designer for easier design

Award-Winning Design Tools

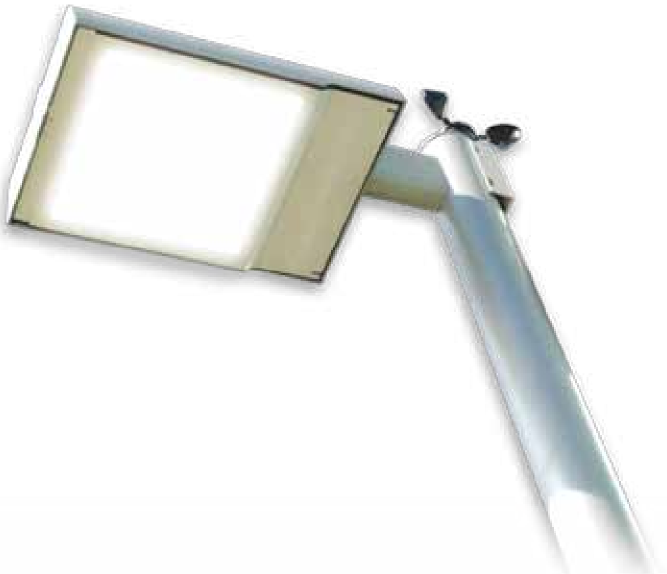
National's unique WEBENCH LED Designer online tool allows for quick and easy selection and simulation of a complete LED and LED driver solution. The tool provides lighting designers a competitive advantage and faster time to market. National's on-demand tools make it easy for designers to explore and learn, compare and select products, and then design and build their system online.

Wide Range of Applications

National has products that fit into a wide range of applications including:

- Downlighting
- Replacement lamps
- Outdoor area fixtures such as street lamps and parking garage lights
- Industrial/commercial such as high bay and low bay fixtures for warehouse lighting
- Portable consumer: flashlights and sports equipment
- Entertainment and projection
- Architectural/decorative fixtures
- LED backlit displays
- Automotive headlamps

... and more



Contents

High-Brightness LED Lighting

Overview

Regardless of type, color, size, or power, all LEDs work best when driven with a constant current. LED manufacturers specify the characteristics (such as lumens, beam pattern, color) of their devices at a specified forward current (I_F), not at a specific forward voltage (V_F).

Most power supply ICs are designed to provide constant voltage outputs over a range of currents (see below); hence, it can be difficult to ascertain which parts will work for a given application from the device datasheet alone.

With an array of LEDs, the main challenge is to ensure every LED in the array is driven with the same current. Placing all the LEDs in a series string ensures that exactly the same current flows through each device.

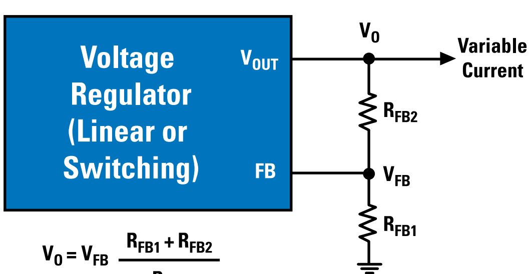
High-Brightness LEDs: Input Voltage and Forward Voltage

Sources of input voltage for LED arrays come from batteries or power supplies that have a certain tolerance. An automotive battery, for example, may supply 8V to 16V depending on the load and the age of the battery. The "silver box" power supply inside a desktop CPU may supply 12V ±10%.

High-brightness (HB) LEDs also give a range of forward voltage. A typical HB LED might be characterized at a forward current of 350 mA. The forward voltage of the LED when I_F = 350 mA is specified with a range that includes a typical value as well as over-temperature maximum and minimum values. To ensure that a true constant current is delivered to each LED in an array, the power topology must be able to deliver an output voltage equal to the sum of the maximum forward voltages of every device placed in the string.

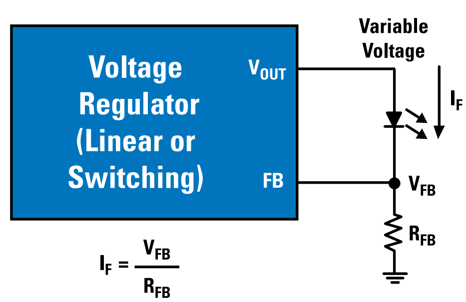
Manufacturers bin their devices for color, brightness, and forward voltage. Binning for all three characteristics is expensive, and forward voltage is often the specification that is allowed to vary the most. Adding this to the shift in forward voltage as the LED die temperature changes gives rise to the need for constant-current regulators that have a wide range of output voltage.

Constant Voltage Regulator



$$V_O = V_{FB}\,\frac{R_{FB1} + R_{FB2}}{R_{FB1}}$$

Constant Current Regulator



$$I_F = \frac{V_{FB}}{R_{FB}}$$

When Input Voltage Exceeds LED Voltage

If input voltage always exceeds the sum of the maximum forward voltages of every LED in a string, then two options are available: linear regulators and buck regulators.

A linear regulator introduces efficiency and thermal drawbacks, but is the simplest design option. In order to provide constant current, the linear regulator must be an adjustable type that uses a pair of feedback resistors. Replacing the top feedback resistor with the LED string and placing a current-sensing resistor in the bottom position "tricks" the former constant voltage source into adjusting the output voltage until enough current flows through the current sensing resistor to equal the feedback voltage of the IC.

Linear regulators have the advantages of simplicity, low parts count, and very little Electromagnetic Interference (EMI). They can deliver constant current as long as the V_F in the LED string does not exceed their dropout-limited output voltage. The disadvantage lies in efficiency and thermal dissipation. Loss in a linear regulator LED driver is approximately equal to $(V_{IN} – n \times V_F) \times I_F$, where "n" is the number of LEDs in the string. At currents of 350 mA and above, the linear solution may require a heatsink, adding cost and size to the design.

The more efficient option when input voltage always exceeds the LED voltage is a step-down or buck regulator. As with linear regulators, this must be an adjustable type, and the same method can be used to turn almost any buck regulator into a constant current source for LEDs. Buck regulators enjoy high efficiency and eliminate the need for a heatsink, at the cost of a more complex circuit and the addition of switching noise. Many recent buck regulators switch at 1 MHz and above, making their external components so small that at currents under 1A they may actually use less space than a linear regulator.

When Input Voltage is Less than LED Voltage

When the minimum forward voltage of all the LEDs in a string will always exceed the maximum input voltage, a step-up, or boost, regulator is needed.

The inductive-boost converter is the simplest regulator that can deliver currents above 350 mA with a varying output voltage. As with linear and buck regulators, a boost converter with a feedback-divider network can be modified to become a constant current source. One important distinction between the buck regulator and boost regulator must be made when the power switch is internal to the control IC. Such monolithic systems have a fixed current limit.

In buck regulators, the internal switch passes the same DC current as the LED. A boost converter differs in that the internal switch sees a higher current that varies with input voltage; the greater the difference between V_{IN} and V_{OUT}, the higher the internal switch current. Care must be taken to evaluate a monolithic boost regulator-based LED drive to make sure that it will not hit the fixed current limit over the range of input voltage.

When Input Voltage Range Overlaps LED Voltage Range

As HB LEDs are adopted into more and more applications, situations will arise when the input voltage varies above and below the forward voltage of the LED string. For these cases, a current regulator is needed that can both buck and boost as required by the input and output conditions. Possible topologies include the buck-boost, SEPIC, Cuk, flyback, and V_{IN} referenced buck-boost (also called the floating buck-boost).

In all of these topologies, the power-switch current exceeds the LED current and varies with input voltage. The same attention to peak switch current must be made over the full range of input voltage, especially if a regulator with an internal power switch and fixed current limit is implemented. For more information about National's LED products, samples, design simulation tools, and more, visit: **national.com/LED**.

LED Drivers Selection Tables

Buck (Step-down) High-Brightness LED Drivers

Product ID	V_{IN} Range (V)	V_{OUT} (V)	I_{LED} (A)	No. of LED	Internal SWITCH	Topology	Key Features	Auto Grade
LM3401 [E, W]	4.5 to 35	Up to 35	3	1 to 9	—	Buck	Dual-side hysteresis, very low reference voltage and short propagation delay, 100% duty cycle	
LM3402/HV [E, W]	6.0 to 42/6.0 to 75	Up to 37/67	0.425	1 to 9/15	✔	Buck	200 mV feedback voltage, fast PWM dimming	
LM3404/HV [E, W]	6.0 to 42/6.0 to 75	Up to 37/67	1	1 to 9/15	✔	Buck	200 mV feedback voltage, fast PWM dimming	
LM3405A [E, W]	3.0 to 22	Up to 20	1	1 to 3	✔	Buck	200 mV feedback voltage, fast PWM dimming, thin package	
LM3406/HV [E, W]	6.0 to 42/6.0 to 75	Up to 37/67	1.5	1 to 9/15	✔	Buck	200 mV feedback voltage, fast PWM or two-wire dimming, true average current control	
LM3407 [E, W]	4.5 to 30	Up to 27	0.35	1 to 7	✔	Floating Buck	Constant frequency PWM with true average current control	
LM3409/HV [E, W]	6.0 to 42/6.0 to 75	Up to 42/75	3.0+	1 to 9/15	—	Buck	External high-side P-FET current source with differential current sensing and analog current adjust, 100% duty cycle	🚗
NEW! LM3414/HV [E, W]	4.5 to 65	Up to 60	1	1 to 15	✔	Floating Buck	Requires no external current sensing resistor and no external compensation, LED current adjustment, temperature foldback	
LM3421 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 16	—	Floating Buck	20 mV to 1.235V adjustable differential current sense voltage, 50 kHz max PWM dimming	🚗
LM3423 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 16	—	Floating Buck	20 mV to 1.235V adjustable differential current sense voltage, 50 kHz max PWM dimming, fault timer, LED ready flag, high-side dimming	🚗
LM3424 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 18	—	Floating Buck	Temperature foldback, synchronizable 50 kHz max PWM dimming	🚗
LM3429 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 20	—	Floating Buck	50 mV to 1:25 adjustable high-side current-sense voltage, analog and PWM dimming	🚗
LM3433 [E, W]	-9.0 to -14	Up to 6	20+	1 to 2	—	Negative SYNC Buck	Negative output voltage capability allows LED anode to be tied directly to chassis for max heat sink efficacy	
NEW! LM3434 [E, W]	-9.0 to -30	Up to 27	20+	1 to 6	—	Negative SYNC Buck	Output current > 20A, PWM frequency capable > 30 kHz, negative output voltage capability allows LED anode to be tied directly to chassis for maximum heat sink efficacy	

Dynamic Headroom Control (DHC) High-Brightness LED Driver Solutions

Product ID	V_{IN} Range (V)	V_{OUT} (V)	I_{LED} (A)	No. of LED	Multi-Output	Internal SWITCH	Topology	Key Features
NEW! LM3464 [E]	12 to 80	Adjustable to 79	3.0+	20 per ch	4 ch	—	Individual Current Regulator + DHC	4-channels with individual current regulation, DHC output interfaces with external power supply to adjust LED supply voltage for maximum efficiency, temperature foldback, analog and PWM dimming

PowerWise® product   [E] Evaluation board   [W] WEBENCH enabled

Boost (Step-up) High-Brightness LED Drivers

Product ID	V_{IN} Range (V)	V_{OUT} (V)	I_{LED} (A)	No. of LED	Multi-Output	Internal SWITCH	Topology	Key Features	Auto Grade
LM3410 [E, W]	2.7 to 5.5	24	2.1[(1)]	1 to 5	—	✔	Boost	Ultra-low stand-by current of 80 nA, internally compensated	
LM3421 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 20	—	—	Boost	20 mV to 1.235V adjustable differential current sense voltage, 50 kHz max PWM dimming	
LM3423 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 20	—	—	Boost	20 mV to 1.235V adjustable differential current sense voltage, 50 kHz max PWM dimming, fault timer, LED ready flag, high-side dimming	
LM3424 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 18	—	—	Boost	Temperature foldback, synchronizable 50 kHz max PWM dimming	
LM3429 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 20	—	—	Boost	50 mV to 1:25 adjustable high-side current-sense voltage, analog and PWM dimming	
LM3431 [E, W]	5.0 to 36	40	0.15	3 x 10	✔	—	Boost	LED protection: short, open, and thermal	

Buck-Boost High-Brightness LED Drivers

Product ID	V_{IN} Range (V)	V_{OUT} (V)	I_{LED} (A)	No. of LED	Multi-Output	Internal SWITCH	Topology	Key Features	Auto Grade
LM3410 [E, W]	2.7 to 5.5	24	2.1[(1)]	1 to 5	—	✔	SEPIC	Ultra-low stand-by current of 80 nA, internally compensated	
LM3421 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 20	—	—	Floating Buck-Boost SEPIC	20 mV to 1.235V adjustable differential current sense voltage, 50 kHz max PWM dimming	
LM3423 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 20	—	—	Floating Buck-Boost SEPIC	20 mV to 1.235V adjustable differential current sense voltage, 50 kHz max PWM dimming, fault timer, LED ready flag, high-side dimming	
LM3424 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 18	—	—	Floating Buck-Boost SEPIC	Temperature foldback, synchronizable 50 kHz max PWM dimming	
LM3429 [E, W]	4.5 to 75	Adjustable	3.0+	1 to 20	—	—	Buck-Boost Flyback SEPIC	50 mV to 1:25 adjustable high-side current-sense voltage, analog and PWM dimming	

Offline High-Brightness LED Driver Solutions

Product ID	V_{IN} Range (V)	V_{OUT} Max (V)	I_{LED} (A)	No. of LED	Multi-Output	Internal SWITCH	Topology	Key Features
LM3445 [E, W]	80 to 270	Adjustable	1+	1 to 14+	—	—	Floating Buck	Integrated TRIAC dim decoder circuit for LED dimming, adaptive programmable offline allows for constant ripple current, no 120/100 Hz flicker

Note [(1)] Specified in I_{SW} PowerWise® product [E] Evaluation board [W] WEBENCH enabled

Key Products Overview

LM3464 – PowerWise® LED Driver with Dynamic Headroom Control

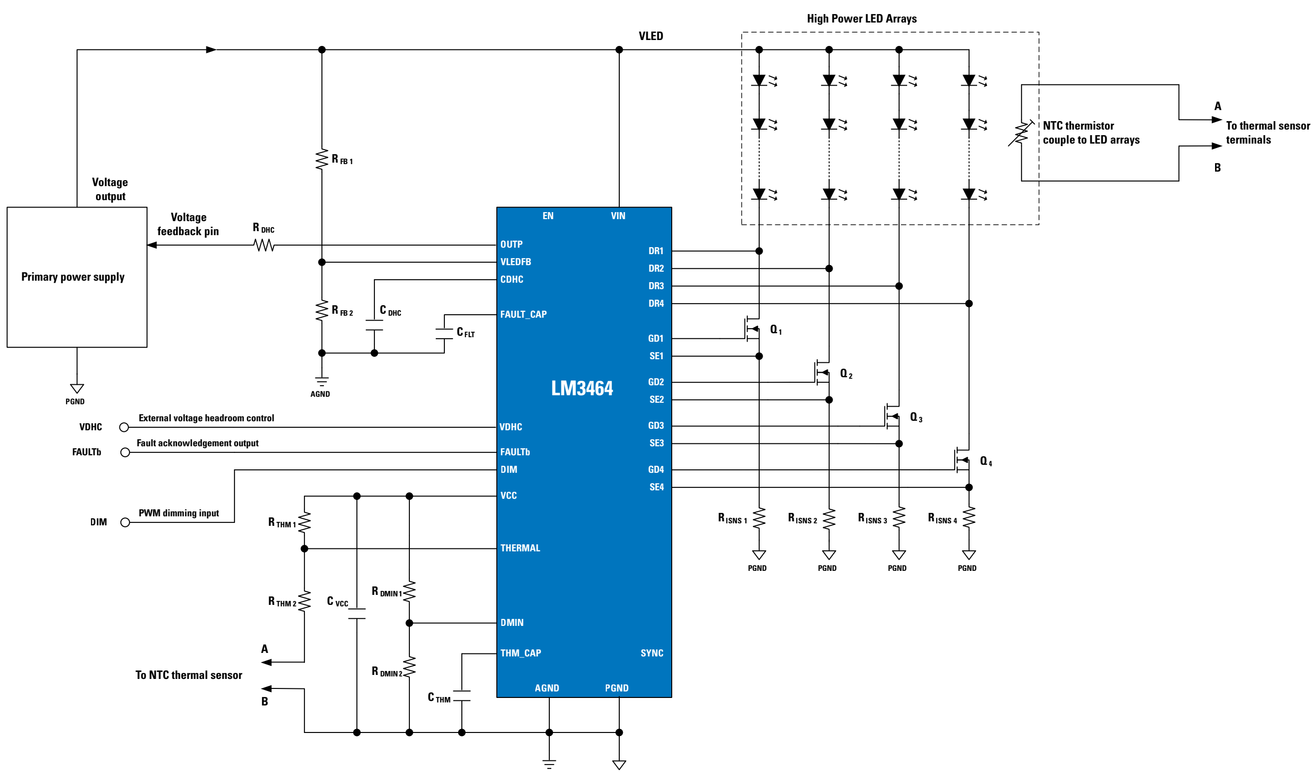
Theory of Operation

- Four individual current regulator channels work in conjunction with external N-channel MOSFETs and sense resistors to accurately drive current for every LED string
- Dynamic Headroom Control (DHC) output interfaces with an external power supply to adjust LED supply voltage to the lowest level adequate to maintain all string currents in regulation, yielding maximized efficiency and reduced system complexity
- Digital Pulse-Width Modulation (PWM)/analog dimming control interface provides thermal foldback and increases system reliability
- Protection features include wide input voltage range (12V to 80V), Under-Voltage Lockout (UVLO), LED open/short circuit, and over-temperature fault signal to the system controller
- Available in eTSSOP-28 packaging

Applications

Ideal for solid-state lighting solutions or multi-string, white light applications such as street lights, high bay/warehouse lighting, automotive headlamps, and office troffers

Typical Application Circuit



LM3421/23/24/29 – PowerWise® N-Channel Controllers for Constant-Current LED Drivers

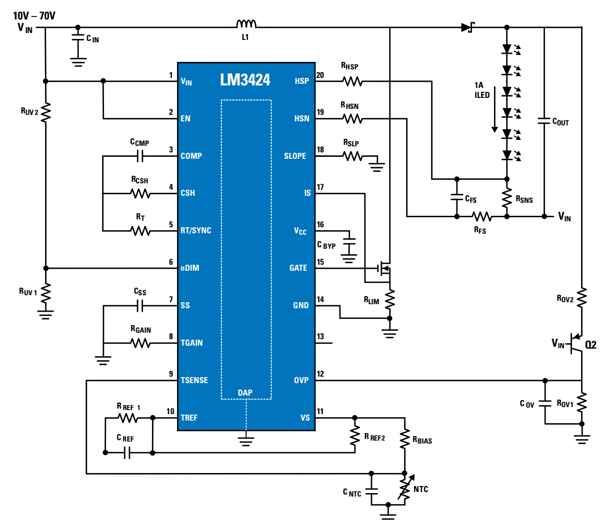
Theory of Operation

- Versatile high-voltage LED driver controllers can be configured in buck, boost, buck-boost (flyback), or SEPIC topologies
- Designed for adjustable-switching frequencies of up to 2.0 MHz
- Fast PWM dimming, cycle-by-cycle current limit, over-voltage protection, and input under-voltage protection
- LM3424 includes an integrated thermal foldback feature to provide a more robust thermal design to extend the life of the LED and increase system reliability

Applications

Ideal for illuminating LEDs in a very diverse, large family of applications

Typical Application Circuit



LM3414/14HV – PowerWise® 1A, 60W Common-Anode-Capable, Constant-Current Buck LED Driver

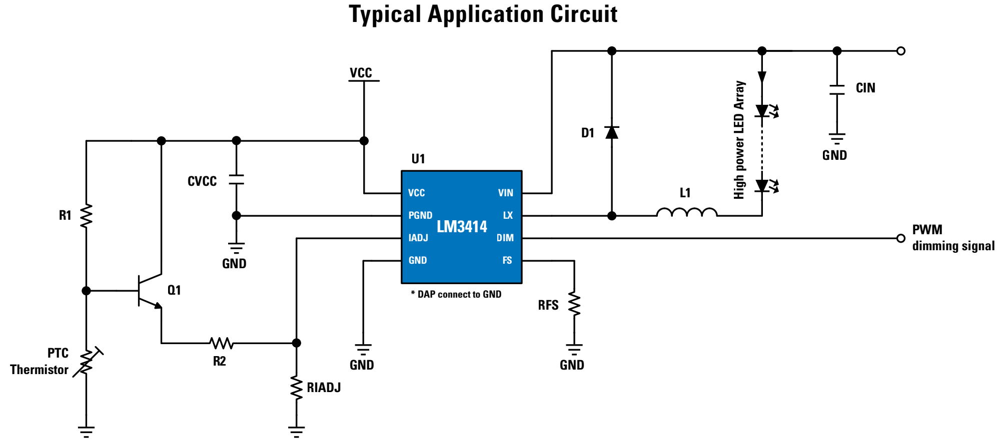
Theory of Operation

- Wide input voltage range (4.5V to 65V)
- Requires no external current sensing resistor and no external compensation, enabling a more compact and simpler solution
- Common-anode capable for minimum wiring
- LED current adjustment (350 mA to 1000 mA) enables precise LED current settings
- Analog dimming and thermal foldback provide a more robust and versatile system
- Supports all-ceramic capacitors
- Pulse-Level Modulation (PLM) control reduces power loss benefitting in high conversion efficiency and true average LED current regulation
- Adjustable constant switching frequency (100 kHz to 1000 kHz), thermal shutdown protection, and V_{CC} UVLO
- Available in power-enhanced PSOP-8 or LLP-8 packaging (3 x 3 mm)

Applications

Ideal for illuminating LEDs in a very diverse, large family of applications, especially space-constrained applications such as MR16 bulbs

Typical Application Circuit



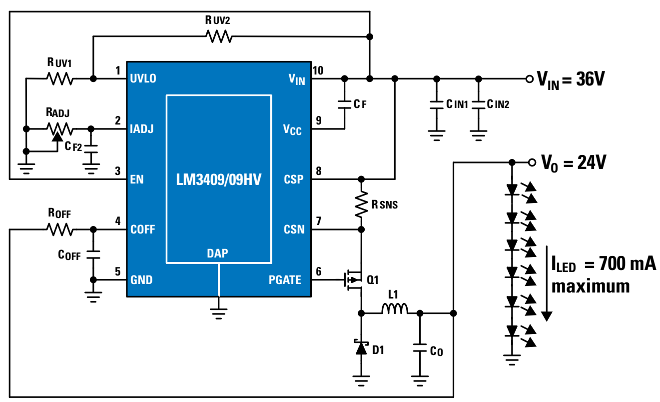
Key Products Overview

LM3409/09HV – PowerWise® PFET Buck Controller for High-Power LED Drivers

Theory of Operation

- P-channel MOSFET (PFET) controllers for step-down (buck) current regulators
- Wide-input voltage range, high-side differential current sense with low adjustable threshold voltage, fast-output enable/ disable function
- Constant Off-Time (COFT) control regulates an accurate constant current without the need for external control-loop compensation
- Analog and PWM dimming are easy to implement and result in a highly linear dimming range with excellent achievable contrast ratios
- UVLO, low-power shutdown, and thermal shutdown
- Can drive LEDs at currents >3A
- Available in eMSOP-10 packaging

Typical Application Circuit



Applications

Ideal for illuminating LEDs in a very diverse, large family of applications

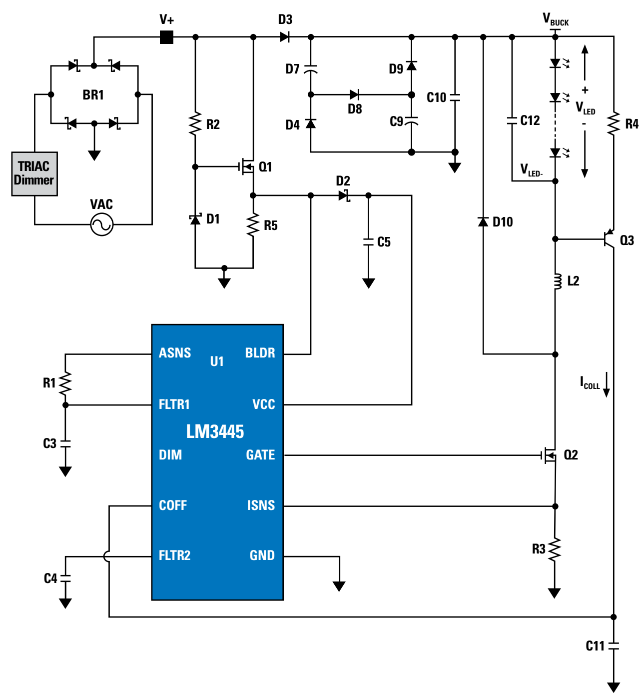
LM3445 – PowerWise® TRIAC Dimmable Offline LED Driver

Theory of Operation

Conventional TRIAC dimmers are designed to interface to a resistive load (halogen or incandescent bulb), while today's LED driver solutions interfaced to a standard wall dimmer produce 120 Hz flicker of the LED and/or do not allow 100:1 dimming.

- LM3445 LED driver decodes the TRIAC chopped waveform and translates the signal to dim the LEDs, achieving a full, wide dimming range without flicker
- Best-in-class dimming performance
- High efficiency
- Maintains ENERGY STAR® power factor requirements in a typical application

Typical Application Circuit



Applications

Ideal for any application where an LED driver must interface to a standard TRIAC wall dimmer

National Offers a Diverse Portfolio of Constant-Current Regulators for Driving LEDs

Applications

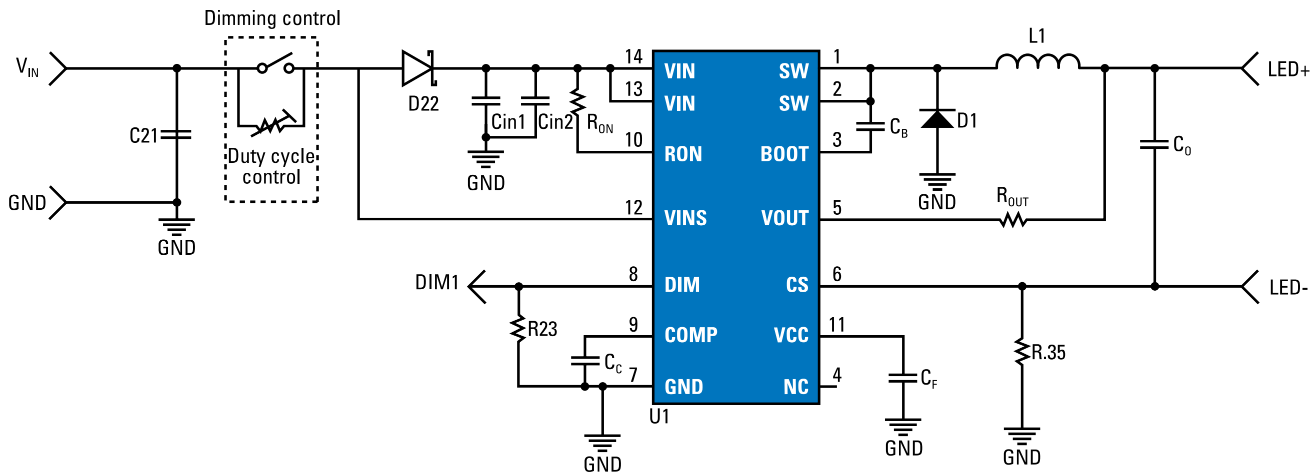
LED Driver	LED Bulbs	Outdoor High-Power Wide Area	Indoor/Downlight Fixtures	Automotive	Display Backlighting	Medical	Entertainment	Portable Consumer	Projectors
LM3401	✔	✔	✔	✔		✔	✔	✔	
LM3402/HV	✔	✔	✔	✔		✔	✔		
LM3404/HV	✔	✔	✔	✔		✔	✔		
LM3405/A	✔	✔	✔	✔		✔		✔	
LM3406/HV	✔	✔	✔	✔		✔	✔		
LM3407	✔	✔	✔	✔		✔		✔	
LM3409/HV	✔	✔	✔	✔		✔	✔		
LM3410	✔			✔	✔	✔		✔	
LM3414	✔	✔	✔	✔		✔	✔	✔	
LM3421/23	✔	✔	✔	✔	✔	✔	✔		
LM3424	✔	✔	✔	✔		✔	✔		
LM3429	✔	✔	✔	✔		✔	✔	✔	
LM3430/32				✔	✔	✔			
LM3431				✔	✔	✔			
LM3433						✔	✔		✔
LM3434						✔	✔		✔
LM3445	✔								
LM3464		✔	✔	✔		✔			

Two-Wire Dimming

LM3406 Two-Wire Dimming

Adding an external input diode and using the internal V_{INS} comparator allows the LM3406/06HV to sense and provide PWM dimming of the LED by chopping of the input voltage. This method is also referred to as "two-wire dimming," and a typical application circuit is shown below.

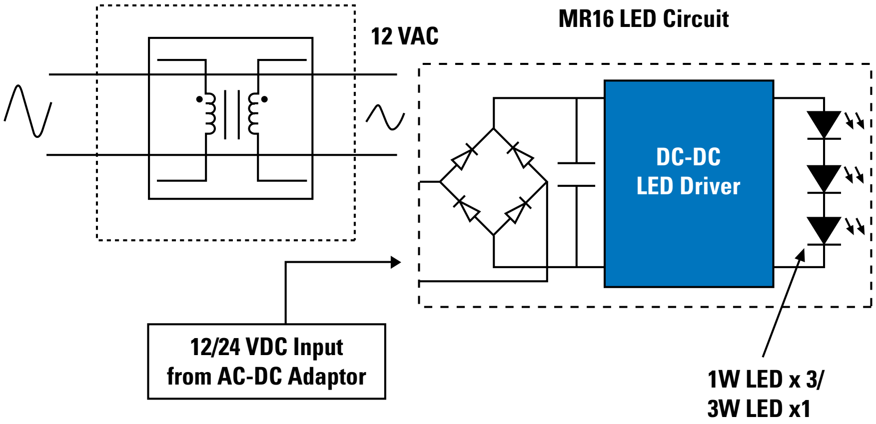
If the V_{INS} pin voltage falls 70% below the V_{IN} pin voltage, the LM3406/06HV disables the internal power FET and shuts off the current to the LED array. The support circuitry (driver, bandgap, V_{CC}) remains active in order to minimize the time needed to turn the LED back on when the V_{INS} pin voltage rises and exceeds 70% of V_{IN}. This minimizes the response time for turning the LED array back on.



The benefit of two-wire dimming: One wire less than traditional PWM dimming, further reducing the wiring cost

MR16

MR16 Basic Architecture



MR16 Driver Solutions

V_{IN}	No. of LEDs	LED Type (W)	I_{LED} (mA)	Recommended Part No.	Key Features
12 to 24 VAC-VDC	1 to 3	1 to 5	>1	**LM3421/29**	Buck-boost architecture
12 to 24 VAC-VDC	1 to 3	1 to 5	>1	**LM3424**	Buck-boost architecture, thermal foldback
12 to 48 VDC	1	5	350	**LM3406**	Two-wire dimming, high efficiency
12 to 24 VDC	3	1	350	**LM3401**	100% duty cycle
12 to 48V	3	5	350	**LM3409**	100% duty cycle, analog dimming
12 VAC	3	1	350	**LM3414**	100% duty cycle, analog dimming
12 VDC/12 VAC	3	1	350	**LM3405A XMK**	Small size, tiny SOT23-6 packaging
12 to 24 VDC	3	1	350	**LM3407**	High efficiency, high precision of LED current
12 VDC/12 VAC	1	3	600	**LM3405A XMK**	Small size, tiny SOT23-6 packaging
12 VDC/12 VAC	1	3	750	**LM3405A XMY**	Thermally enhanced package, eMSOP-8

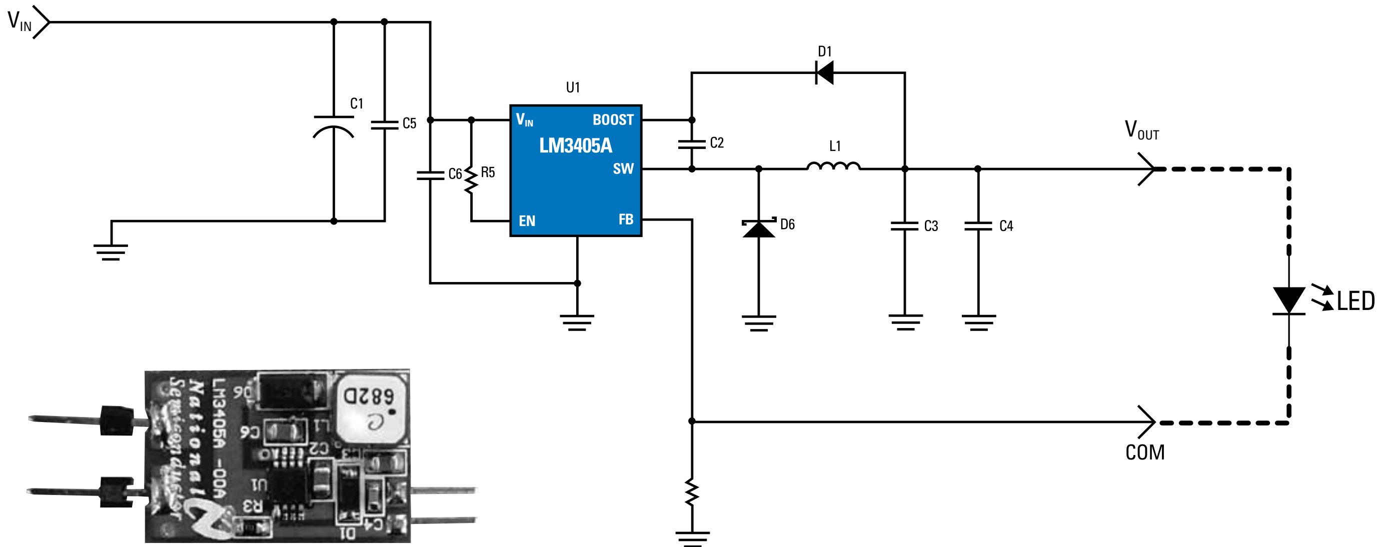
High-Brightness LED Applications

LED Bulbs

Design 1: MR16 Using LM3405A

Description:

- This circuit is designed to drive a 3W high-brightness LED from an input of 12 VDC/12 VAC for halogen MR16 lamp replacement applications.



Test Data:

1: Output Voltage & Current

Parameter		Reading	
V_{IN}	Load	V_{OUT}	I_{LED}
12 VDC	1 LED	**3.8V**	**0.70A**

2: Efficiency

	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
12V	12V	0.274A	3.80V	0.70A	**80.9%**

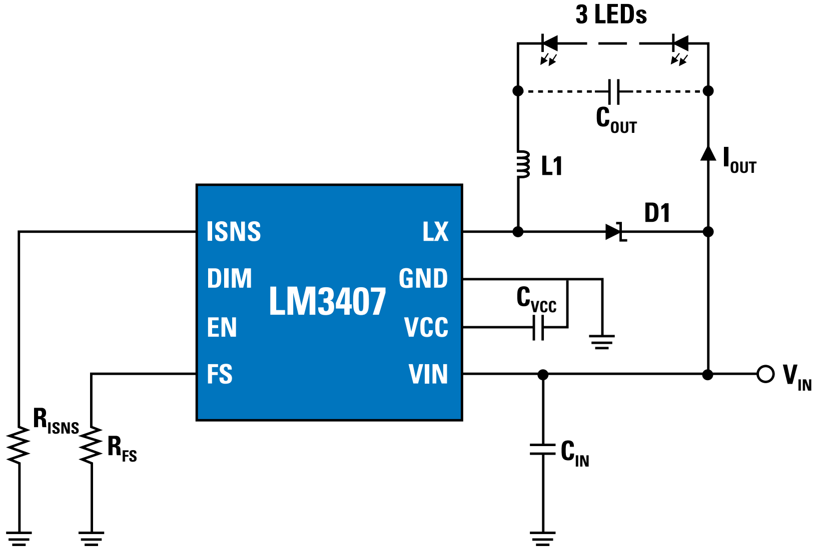
BOM (Main Components)

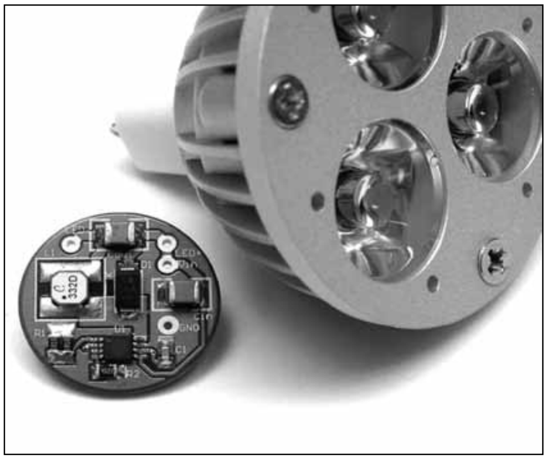
Item	Designation	Description	Part No.	Vendor
1	**U1**	LED driver IC	LM3405A (eMSOP-8)	National
2	**C1**	16V, 220 µF, 8 x 7 mm	SG or YK, 220 µF, 16V	Lelon or Rubycon
3	**L1**	Inductor 6.8 µH, 0.095 Ω, 2.6A	LPS6225-682MLB	Coilcraft
4	**Co**	CAP0805, 0.47 µF	GRM188R71C474KA88	Murata

Design 2: MR16 Using LM3407

Description:

- This circuit is designed to drive an array of 3 series-connected 1W LEDs from an input of 12 VDC/12 VAC for MR16 lamp replacement applications.





Test Data:

1: Output Voltage & Current

Parameter		Reading	
V_{IN}	Load	V_{OUT}	I_{LED}
12 VDC	3 LEDs	**9.71V**	**0.35A**

2: Efficiency

	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
12V	12.01V	0.30A	9.71V	0.35A	**94.06%**

BOM (Main Components)

Item	Designation	Description	Part No.	Vendor
1	**U1**	LED driver IC	LM3407 (eMSOP-8)	National
2	**L1**	Inductor 33 µH, 0.58A	LPS-4018-333ML	Coilcraft
3	**C_{IN}**	Cap MLCC 50V, 4.7 µF, X7R	GRM32ER71H475K88L	Murata
4	**C_{OUT}**	Cap MLCC 25V, 2.2 µF, X7R	GRM31MR71E225MA93	Murata

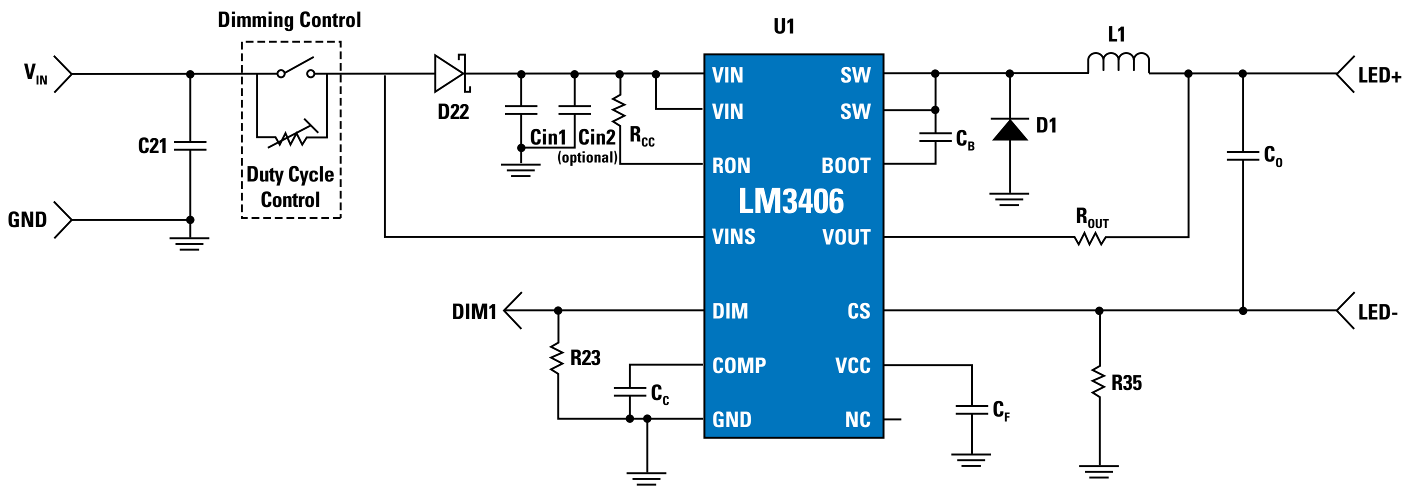
High-Brightness LED Applications

LED Bulbs

Design 3: MR16 with Two-Wire Dimming Driven by the LM3406

Description:

- This circuit is designed to drive a 1.5A high-brightness LED from an input of 12 VDC for MR16 lamp replacement applications.
- The two-wire dimming feature of LM3406 enables PWM dimming over the power input line.



Test Data:

1: Output Voltage and Current

Parameter		Reading	
V_{IN}	Load	V_{OUT}	I_{LED}
12 VDC	2 LEDs	**4.20V**	**1.50A**

2: Efficiency

	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
12V	12V	0.62A	4.20V	1.50A	**84.68%**

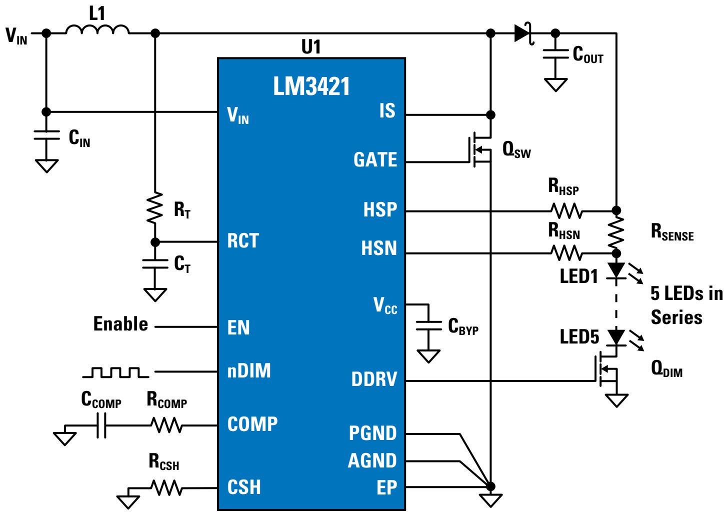
BOM (Main Components)

Item	Designation	Description	Part No.	Vendor
1	**U1**	LED driver IC	LM3406 (eTSSOP-14)	National
2	**L1**	15 µH, 2.2A, 47 mΩ	SLF10145T-150M2R2-P	TDK
3	**Cin1**	3.3 µF, 50V	C3225X7R1H335M	TDK
4	**Co**	0.15 µF, 50V	C3216X7R1H105M	TDK

QR111, PAR30 and PAR38

Description:

- This circuit is designed to drive an array of 5 to 8 series-connected 3W LEDs from an input of 12 VDC/12 VAC for existing QR111, PAR30/38 luminaire form factors.
- Since the total forward voltage of the LED string is higher than the input voltage, LM3421 is configured in a boost topology.



Test Data:

1: Output Voltage & Current

Parameter		Reading	
V_{IN}	Load	V_{OUT}	I_{LED}
12 VDC	5 LEDs	**19.98V**	**0.72A**

2: Efficiency

	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
12V	12V	1.27A	19.98V	0.72A	**94.50%**

BOM (Main Components)

Item	Designation	Description	Part No.	Vendor
1	**U1**	Low-side controller for constant-current LED drivers	LM3421 (eTSSOP–16)	National
2	**L1**	15 µH	7447709150	Coilcraft
3	**C_{IN}**	150 µF/50V	Aluminum eletrolytic capacitor, EEEFK1H151P	Panasonic
4	**C_{OUT}**	150 µF/50V	Aluminum eletrolytic capacitor, EEEFK1H151P	Murata

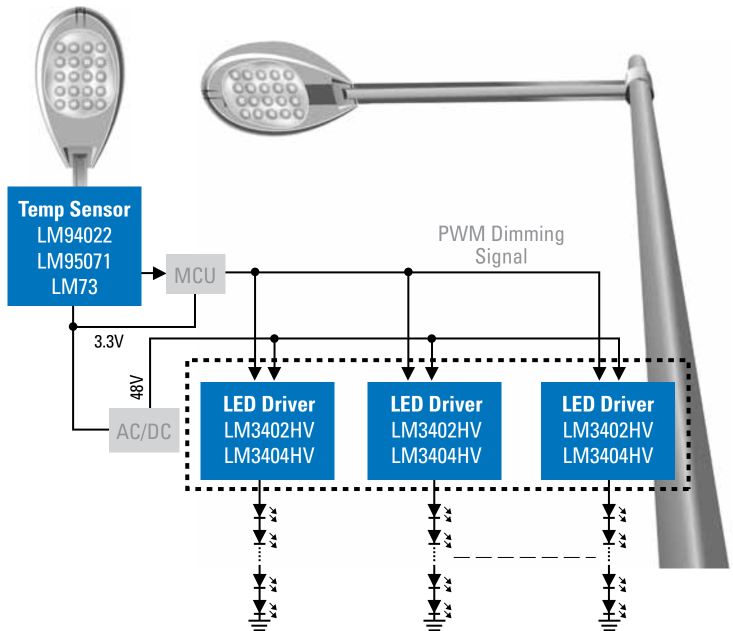
High-Brightness LED Applications

Outdoor High-Power Wide Area

48V Bus Street Lamp

Key Benefits of LM3402/4/6HV in 48V (or higher) Bus LED Street Lamp System

- Wide input voltage range (6V to 42V) or (6V to 75V)
  - Maximizes the number of LEDs per string (~10 to 12 LEDs in series for 1 LED driver)
  - Lower system solution cost
- Ultra-high-efficiency LED driving solution
  - 96% + efficiency with 10 LEDs connected in series
  - Enhanced thermal performance in the harsh street lamp working environment
- No compensation required
  - Easy to use

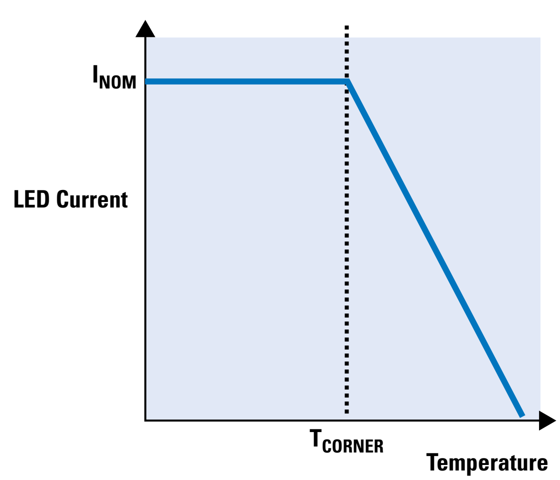


LED Street Lamp Architecture

LM3424 with Integrated Temperature Management

- Temperature foldback
  - Eliminates the need for external thermal management circuitry
  - Increases LED lifetime, allowing for a more robust and reliable system solution
  - WEBENCH® LED Designer online tool with thermal management feature available to implement temperature foldback
    - Ease of design on a system level

The Concept:
The thermal foldback feature lowers regulated current as the temperature increases to optimize the LED lifetime. The feature includes two parameters: A temperature corner (Tcorner) after which the nominal operating current is reduced and the slope corresponding to the amount of LED current decreases per temperature. The LM3424 allows the user to program both the breakpoint and slope of the thermal foldback profile using external resistors.

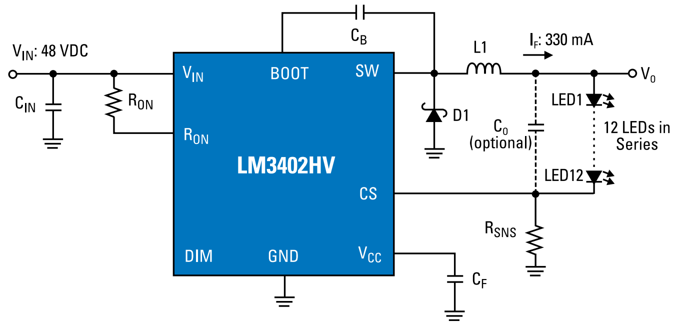


Street Lamp

Design 1: 1W LED String Using LM3402HV

Description:

- This circuit is designed to drive an array of 10 to 12 series-connected 1W LEDs from a 48 VDC source.
- Multiple LM3402HV LED drivers can be used in the system, depending on the street lamp's output wattage.
- Each LM3402HV LED driver provides constant current for a single LED string. This enables consistent brightness of each LED in the LED street lamp.



Test Data:

1: Output Voltage & Current

Parameter		Reading	
V_{IN}	Load	V_{OUT}	I_{LED}
48 VDC	12 LEDs	**38.20V**	**0.33A**

2: Efficiency

	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
48V	47.91V	0.27A	38.20V	0.33A	**98.04%**

BOM (Main Components)

Item	Designation	Description	Part No.	Vendor
1	**U1**	75V, 0.5A LED driver IC	LM3402HV (SOIC-8 or PSOP-8)	National
2	**L1**	18.5 x 15.4 x 7.1 mm 330 µH, 1.9A, 0.56Ω	DO5022P-334	Coilcraft
3	**Cin**	2.2 µF/100V/1812	C4532X7R2A225M	TDK
4	**Co**	0.15 µF, 100V, 1206	C3216X7R2A154M	TDK

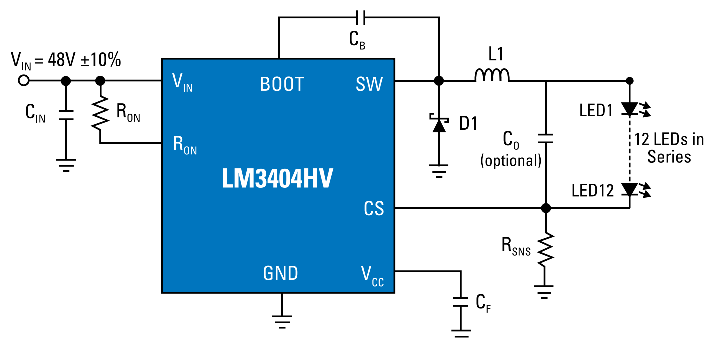
High-Brightness LED Applications

Outdoor High-Power Wide Area

Design 2: 3W LED String Using LM3404HV

Description:

- This circuit is designed to drive an array of 10 to 12 series-connected 3W LEDs from a 48 VDC source.
- Multiple LM3404HV LED drivers are used in the LED street lamp system, depending on the street lamp's output wattage.
- Each LM3404HV LED driver provides constant current for a single LED string. This guarantees consistent brightness of each LED in the LED street lamp.



Test Data:

1: Output Voltage & Current

Parameter		Reading	
V_{IN}	Load	V_{OUT}	I_{LED}
52 VDC	12 LEDs	**41.975V**	**1.071A**

2: Efficiency

	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
52V	51.97V	0.847A	41.975V	1.017A	**96.97%**

BOM (Main Components)

Item	Designation	Description	Part No.	Vendor
1	**U1**	75V, 1.2A LED driver	LM3404HV (SOIC-8 or PSOP-8)	National
2	**L1**	Inductor 220 µH, 0.229Ω, 2.2A	MSS1278-184KL	Coilcraft
3	**Cin**	2.2 µF/100V/1812	C4532X7R2A225M	TDK
4	**Co**	0.15 µF, 100V, 1206	C3216X7R2A154M	TDK

EMI Design for LED Street Lamp Application

The LM3402HV circuitry shown in ***Figure 1*** is based on a street lamp application. The input is 48 VDC and the output is 12 series-connected 1W LEDs. To address the EMI concerns, the schematic and PCB layout were modified. As a result of the modifications, as shown in ***Figure 2*** below, better EMI performance was achieved and the design passed the EN55022 standard.

The modifications are:

1: One resistor Rz (50 Ω) is added between the SW pin and Cb pin. This changes the SW node waveform from ***Figure 3*** to ***Figure 4***. The criterion of Rz selection is dependent on the SW turn-on slew rate and its ringing. The smaller the ringing, the better.

2: 1 µF output cap is added across LED connection port.

3: Input loop area should be kept as small as possible, which is shown in the blue-dashed area of ***Figure 5***. C_{IN} should be connected with the anode of catch diode directly.

4: The SW node should be kept as short as possible.

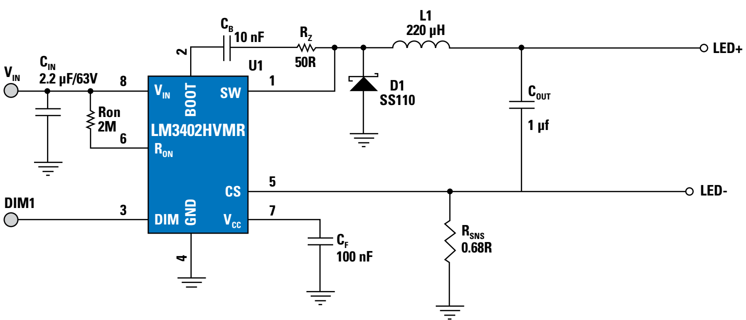


Figure 1

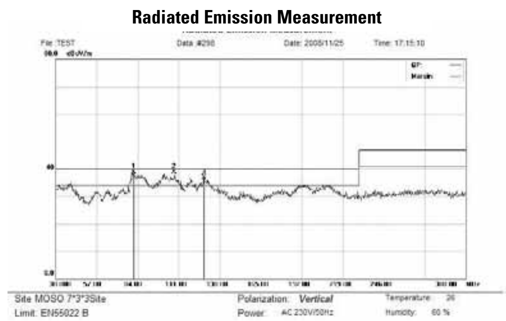


Figure 2

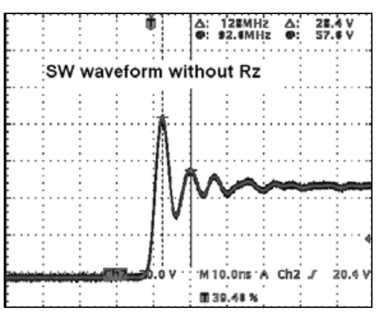


Figure 3

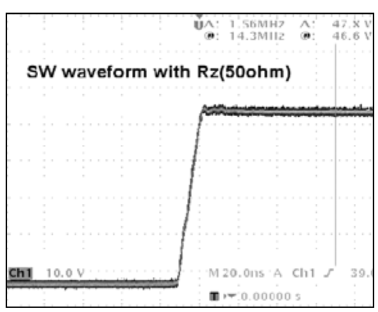


Figure 4

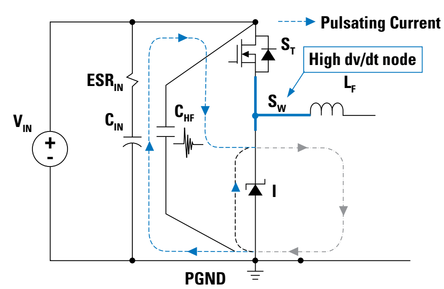


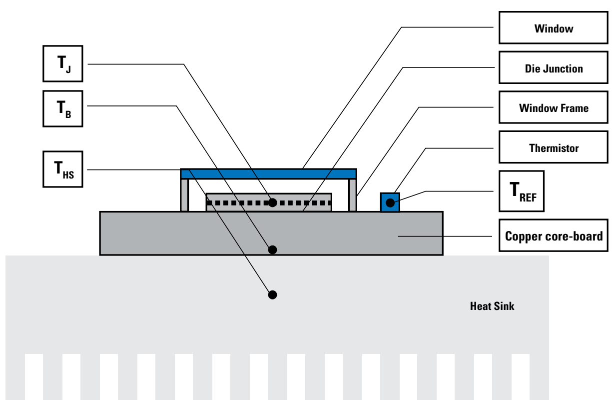
Figure 5

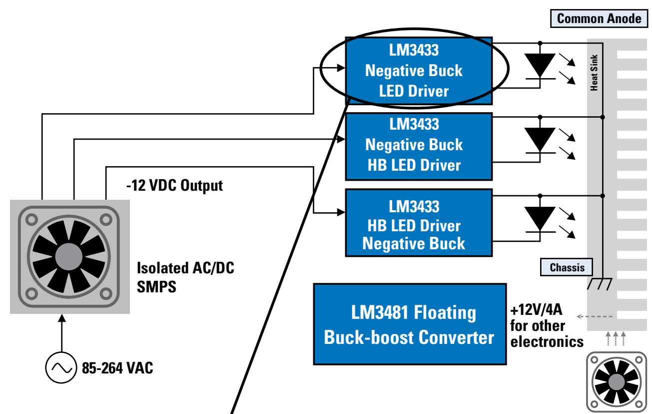
High-Brightness LED Applications

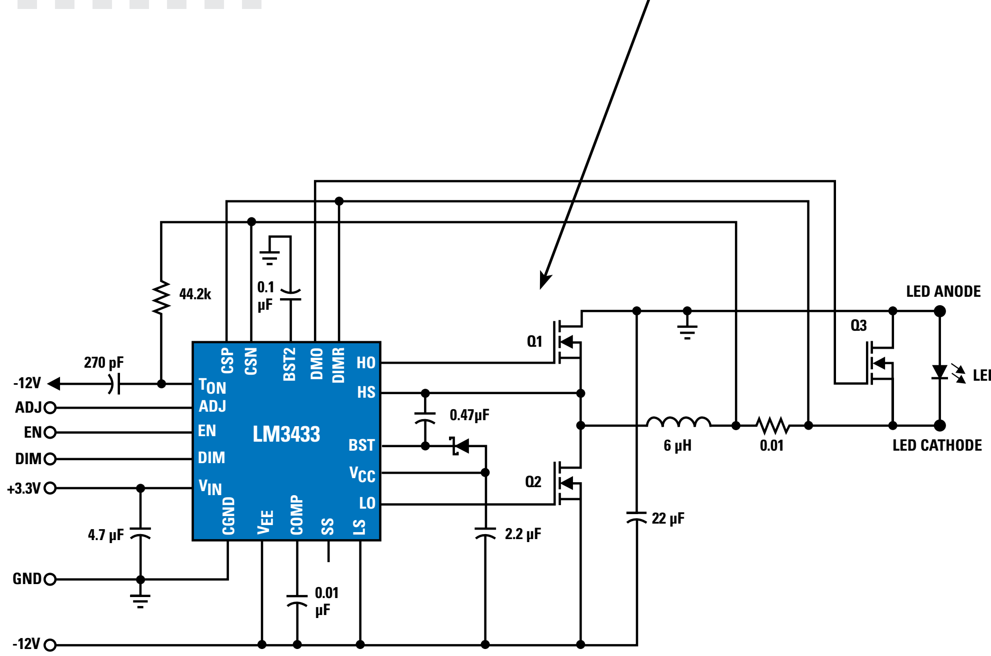
Portable Projectors

Portable Projector

- The LM3433/34 is a high-power constant-current LED driver controller which employs a negative synchronous buck topology, making it ideal for applications where a common-anode LED system is used for high current output.
- An example power architecture of a portable projector using the LM3433 is shown below. The -12 VDC isolated AC/DC SMPS is used for powering LM3433 LED drivers while the LM3481 floating buck-boost is used to generate positive outputs for other logic and interface.





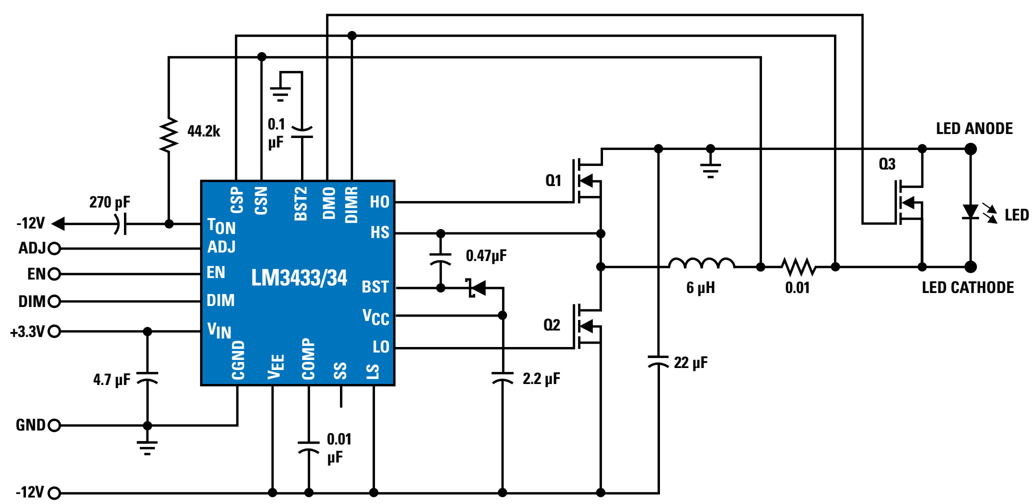


LED Projector Using LM3433/34

Description:

- This circuit is designed to drive a high-brightness common-anode LED module from a -12 VDC source (LM3433) or -20 VDC source (LM3434).
- In LED-based portable projector systems, green, blue, and red high-brightness common-anode LED modules are used as light sources. Each color requires one LM3433/34 driver.

Typical Application Circuit



Test Data:

1: Output Voltage and Current

Parameter		Reading	
V_{IN}	Load	V_{OUT}	I_{LED}
-12 VDC	1 LED	**4.60V**	**6A**

2: Efficiency

	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
-12V	-12V	2.47A	-4.60V	6A	**93%**

BOM (Main Components)

Item	Designation	Description	Part No.	Vendor
1	**U1**	Common-anode-capable high-brightness LED driver with high-frequency dimming	LM3433 (LLP-24)	National
2	**L2**	12 µH, 14A	GA3252-AL	Coilcraft
3	**C3**	150 µF, 16V	16SA150M	MULTICAP
4	**C4**	1210 22 µF x 2, 16V	GRM32ER61C226KE20L	Murata
5	**C6**	1210 47 µF, 16V	GRM32ER61C476ME15L	Murata
6	**MOSFET (Q1,Q2,Q3,Q4)**	PowerPAK 30V, 9.5 mΩ	Si7386DP	Vishay
7	**LED**	6A	PT39	Luminus

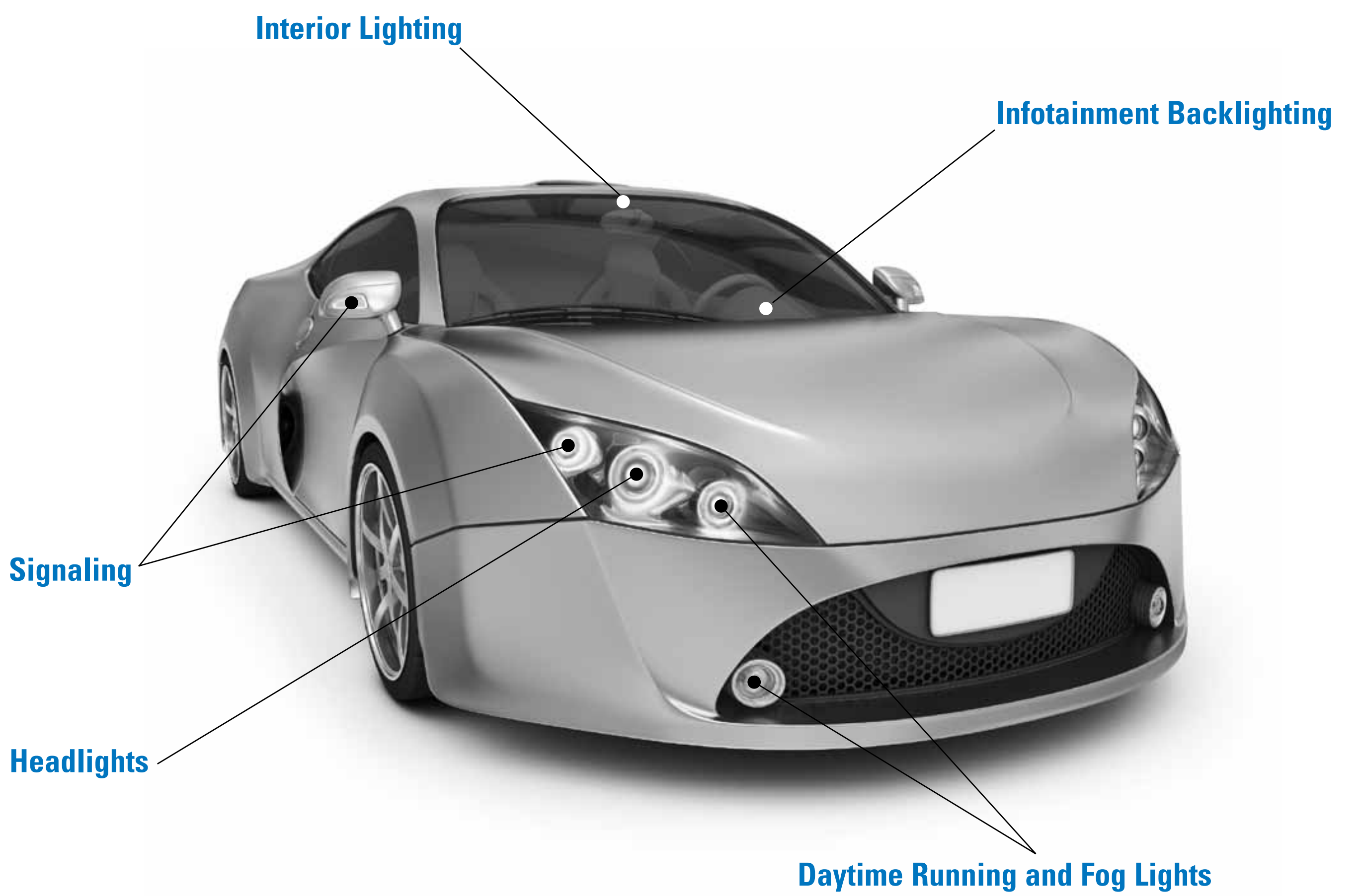
High-Brightness LED Applications

Automotive Lighting

From headlights to LCD backlighting in infotainment systems, LEDs are an integral part of the driving experience. National's portfolio of LED drivers offers key features like PWM dimming, accurate UVLO, and high-side current sensing.

Plus, low LED ripple current and external oscillator sync capabilities allow designers to reduce issues with EMI. These LED drivers provide maximum efficiency and effectiveness in any automotive lighting system.

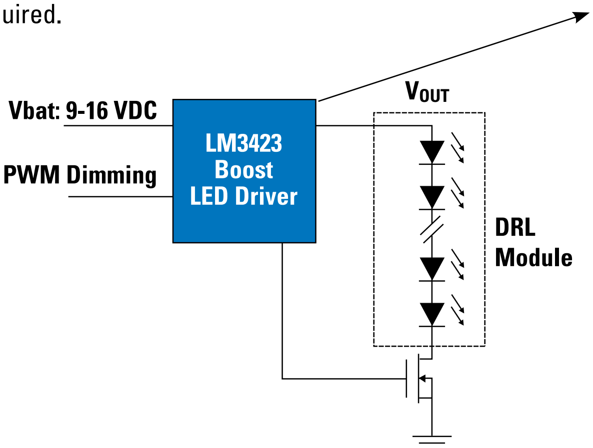
Features	Benefits
High efficiency	Better thermal management
High-side current sensing	LEDs grounded to chassis for better thermal dissipation
Accurate current control	Extends LED lifetime
PWM and analog dimming	Easily reduces current when battery is low to avoid excessive battery drain
Wide voltage range	Stable under instant on, low and high battery, high voltage transients
External oscillator sync capability	External spread spectrum for low EMI



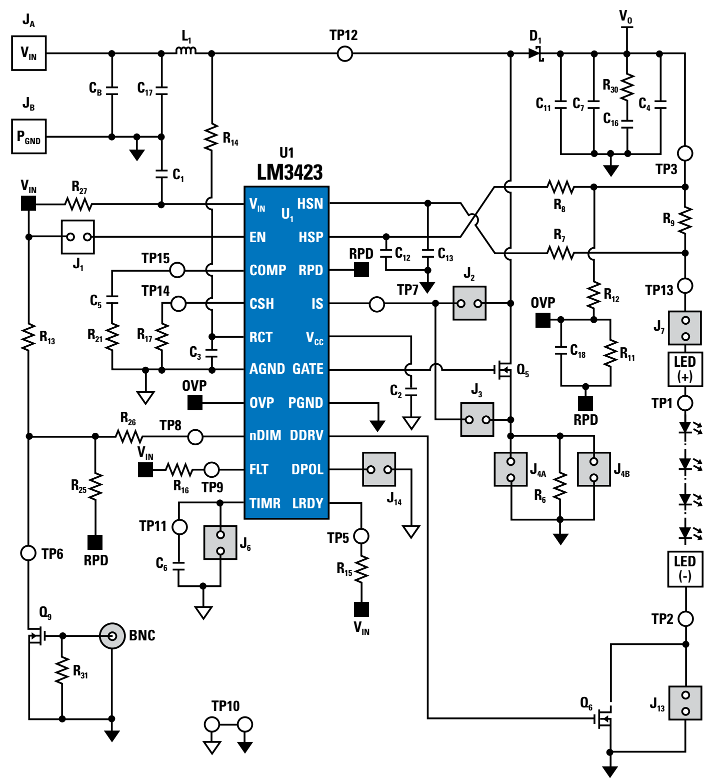
Design 1: Driving Daytime Running Lamp (DRL) with LM3423 Boost LED Driver

Description:

- This circuit is designed to drive a single string of 12 series-connected 1W LEDs from the battery input for daytime running lamps (DRL) in passenger cars.
- Since the total forward voltage of the LED string is higher than the battery input voltage, a boost (step-up) LED driver is required.



DEMO Board



Test Data:

1: Output Voltage & Current

Parameter		Reading	
V_{IN}	Load	V_{OUT}	I_{LED}
12 VDC	12 series-connected 1W LEDs	**46V**	**0.40A**

2: Efficiency

	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
12V	12V	1.65A	46V	0.40A	**92.93%**

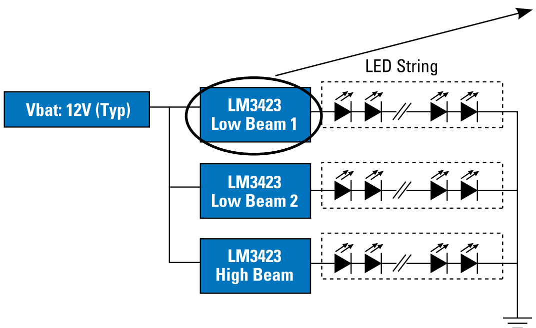
BOM (Main Components)

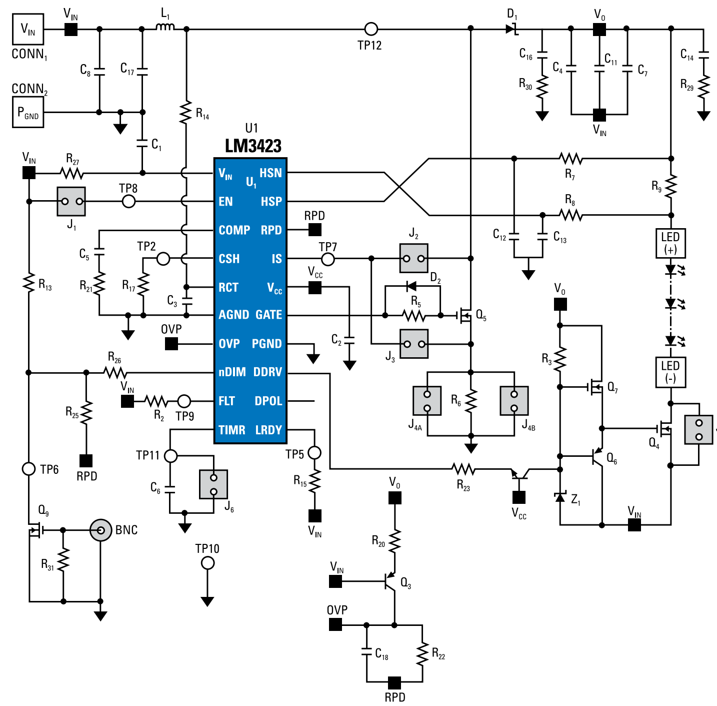
Item	Designation	Description	Part No.	Vendor
1	**U1**	Low-side controller for constant-current LED drivers	LM3423 (eTSSOP-20)	National
2	**L1**	22 µH	DO5040H	Coilcraft
3	**C8 (Cin)**	330 µF, 35V 5 mm	ECA-1VM331	Panasonic
4	**C7 (Cout1)**	330 µF, 35V 5 mm	ECA-1VM331	Panasonic
5	**C11 (Cout2)**	1210 10 µF, 25V	ECJ-4YB1E106M	Panasonic

Design 2: Headlamp Using LM3423 Buck-Boost LED Driver

Description:

- This circuit is designed to drive a single string of 6 series-connected 3W LEDs from both a 12V and a 24V bus battery input for automotive headlamp applications.
- Since the total forward voltage drop of the LED string can be either higher or lower than the input voltage, a buck-boost LED driver is required.





Test Data:

1: Output Voltage & Current

Parameter		Reading	
V_{IN}	Load	V_{OUT}	I_{LED}
6 to 32 VDC	20V at 1A	**20V**	**1A**

2: Efficiency

	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
12V	12V	1.87A	20V	1A	**88.98%**
24V	24V	0.93A	20V	1A	**89.51%**

BOM (Main Components)

Item	Designation	Description	Part No.	Vendor
1	**U1**	Buck-boost controller for constant-current LED drivers	LM3423 (eTSSOP-20)	National
2	**L1**	22 µH	DO5040H	Coilcraft
3	**C8 (Cin)**	330 µF/35V 5 mm Lead	ECA-1VM331	Panasonic
4	**C7 (Cout1)**	330 µF/35V 5 mm Lead	ECA-1VM331	Panasonic
5	**C11 (Cout2)**	1210 10 µF, 25V	ECJ-4YB1E106M	Panasonic

Design 3: LED Backlighting Applications Using LM3431

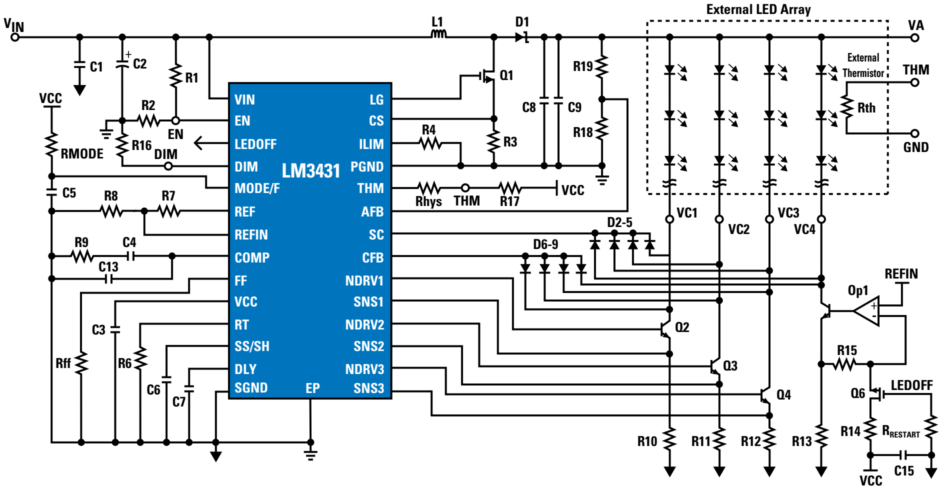
LED Backlighting Infotainment

LED Backlighting for Dashboards

Description:

- This circuit is designed to drive four channels of 8 series-connected 140 mA LEDs from a 12V bus battery input for automotive LED backlighting in a TFT display.

V_{IN}: 8V to 18V, 4 Strings of 8 LEDs, 140 mA per String



Test Data:

1: Output Voltage & Current

Parameter		Reading	
V_{IN}	Loading	V_{OUT}	I_{LED}
8 to 18 VDC	4 strings of 8 LEDs, Vf: 3.2V	**25.60V**	**0.14A**

2: Efficiency

	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
12V	12V	0.34A	25.60V	0.14A	**88%**

BOM (Main Component)

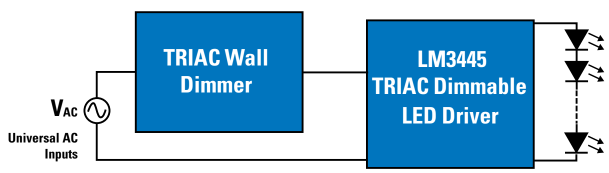
Item	Designation	Description	Part No.	Vendor
1	**U1**	Boost controller for multi-channel constant-current LED drivers	LM3431 (eTSSOP-28)	National
2	**L1**	7 µH 3.1A inductor	MSS1038-702NL	Coilcraft
3	**C2 (Cin_1)**	10 µF 50V electrolytic	UUD1H100MCL	Nichicon
4	**C1 (Cin_2)**	1 µF 50V B ceramic	GRM32RB11H105KA01	Murata
5	**C3 & C8 (Cout)**	2 x 4.7 µF 50V X7R ceramic	GRM32ER71H475KA88L	Murata
6	**Q1**	60V 200 mA N-channel MOSFET	2N7002K	Vishay

High-Brightness LED Applications

TRIAC Dimming

TRIAC Dimmable LED Lamp Using LM3445

- The TRIAC phase-control dimmer is today's most popular and common dimming method, but it is designed to interface to a purely resistive load, such as incandescent or halogen light bulbs. Since an LED does not appear as a resistive load to the TRIAC dimmer, dimming an LED using a conventional TRIAC wall dimmer does not achieve good dimming performance.
- National's LM3445 TRIAC dimmable offline LED driver overcomes the issue and enables LEDs to be used as a direct replacement for incandescent or halogen lamp systems which are currently interfaced to a TRIAC wall dimmer. The LM3445 is an offline solution that offers 100:1 full-range, uniform dimming capability, is free of flicker at 100/120 Hz, and supports master/slave operation.



Test Data:

1: Output Voltage & Current

Parameter		Reading	
V_{IN}	Load	V_{OUT}	I_{LED}
110 VAC	12 LEDs	**46 VDC**	**0.35A**

2: Efficiency

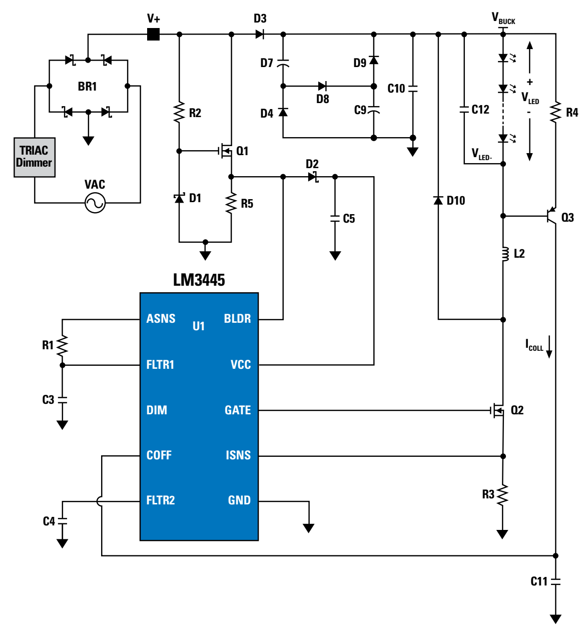
	Reading				
Input Voltage	V_{IN}	I_{IN}	V_{OUT}	I_{LED}	Efficiency
110 VAC	—	—	46.0V	0.35A	**84.20%**

TRIAC Dimmable LED Lamp with LM3445

Description:

- This design is configured to support 90 VAC to 135 VAC inputs to drive 7 or 8 series-connected LEDs at an average current of 350 mA for TRIAC dimmable LED lamp applications.

Demo Board



BOM (Main Components)

Item	Designation	Description	Part No.	Vendor
1	**U1**	LED driver controller	LM3445MM (mini SOIC-10)	National
2	**BR1**	Bridge rectifier, SMT, 400V, 800 mA	HD04-T	Diode
3	**L2**	Inductor. SHLD. SMT, 1A, 470 µH	MSS1260-474KLB	Coilcraft
4	**C7, C9**	Cap, AL, 200V, 105C, 20%, 33 µF	EKXG201ELL330MK15L	UCC
5	**D4, D9**	Diode, FR, SOD123, 200V, 1A	RF071M2S	Rohm
6	**D10**	Diode, FR, SMB, 400V, 1A	MURS140T3G	On Semiconductor
7	**Q1, Q2**	XSTR, NFET, DPAK, 300V, 4A	FQD7N30TF	Fairchild

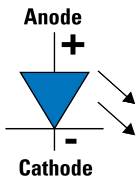
Light Matters: *The ABC's of LEDs*

Read Parts 1-4 in full at national.com/led under the Apps tab

When it comes to lighting, it is quite easy to imagine the impact of globally improving the efficiency of lighting sources by 10%. But what if it could be improved by 1000%? The use of newly enhanced LEDs as lighting sources has the potential to achieve these efficiency improvements while maintaining outstanding performance and reliability that supersede many of the currently used sources.

Part 1, The ABCs of LEDs, sheds some light on the basics of LEDs physical structure, colors, efficiency, applications, and drivers. Learn more about…

- Anatomy
- Color
- Efficiency
- Applications
- Drivers

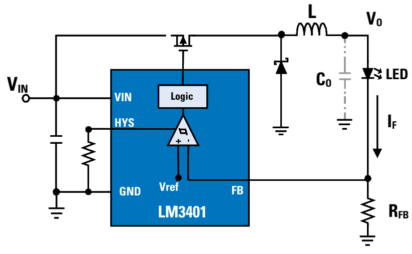


Many characteristics make buck-based regulators attractive LED drivers. They are simple to configure as a current source and can be realized with minimum component counts, which simplifies the design process, improves the drivers' reliability, and reduces cost. Buck-based LED drivers also provide configuration flexibility since they are compatible with multiple control schemes. They also allow for high-speed dimming as well as wide dimming ranges since they can be configured without output capacitance and are well-matched to various dimming approaches including shunt dimming. All these features make buck-based (step-down) LED drivers the topology of choice whenever the application permits.

Part 2, Buck Whenever Possible, discusses why a constant-current buck converter should be the first preference when it comes to switch-mode LED drivers. Learn more about…

- Switching Regulators
- Constant-Current Power Stage
- Control-Loop Schemes

What if the application does not permit a buck configuration? Applications such as residential and commercial lighting require thousands of lumens, creating a need to drive LED strings.

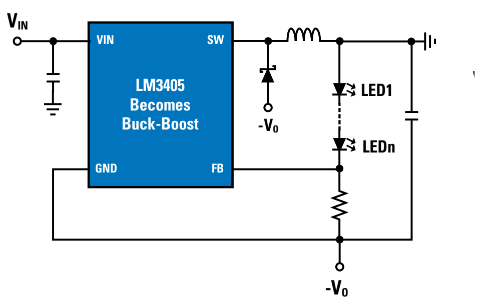


The total forward voltage drop of an LED string is equal to the sum of the forward voltage drops of all the LEDs in the string. In some cases, the input voltage range of the system can be lower than the forward voltage drop of the LED string, or it can vary so that sometimes it's lower and sometimes it's higher. These scenarios would require either boost or buck-boost switching regulators.

Part 3, When to Buck and Buck-Boost, investigates larger LED displays and the applications space for other converter topologies. Learn more about…

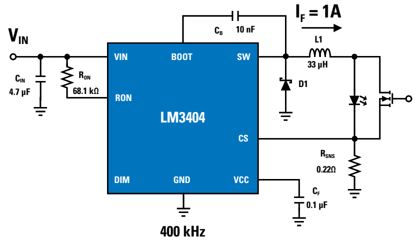
- Challenges of Boost and Buck-Boost
- Other Topologies

Whether you drive LEDs with a buck, boost, buck-boost, or linear regulator, the common thread is drive circuitry to control the light output. A few applications are as simple as ON and OFF, but a greater number of applications call for dimming the output between 0 and 100%, often with fine resolution. The designer has two main choices: Adjust the LED current linearly (analog dimming), or use switching circuitry that works at a frequency high enough for the eye to average the light output (digital dimming). Using pulse-width modulation (PWM) to set the period and duty cycle is perhaps the easiest way to accomplish digital dimming, and a buck regulator topology will often provide the best performance.



Part 4, PWM Dimming, describes how to best implement the dimming function. Learn more about…

- PWM Versus Analog Dimming
- Dimming Frequency Versus Contrast Ratio
- Dimming with a Switching Regulator
- Fast PWM with Boost and Buck-Boost



Dimming Techniques for Switched-Mode LED Drivers

The exponential growth of LED lighting has ushered in a vast selection of integrated circuit devices to provide controlled power to LEDs. No longer acceptable to an energy-conscious world, switched-mode LED drivers have long since replaced power-hungry linear current sources as the standard. Applications from flashlights to stadium scoreboards all require precise control of regulated currents. In many instances, real-time changes in LED output intensity are required. This function is commonly referred to as dimming control. This article describes some basic LED theory and several techniques used to provide dimming control to switched-mode LED drivers.

LED Brightness and Color Temperature

LED Brightness

The concept of the brightness of visible light from an LED is fairly easy to understand. Assigning a numerical value to the perceived brightness of an LED's output can simply be measured in units of luminous flux density, called candelas (cd). The total power output of an LED is a measurement of the amount of Lumens (lm).

It is also important to understand that average forward LED current determines the brightness of an LED.

Figure 1 shows the relationship between forward LED current vs. lm output for a certain LED. The relationship is remarkably linear over useable ranges of I_F or forward current. Note the nonlinearity appearing as I_F increases. Reduced efficacy in Lumens per Watt arises as the operating current exceeds the linear range. Operation above the linear range results in output power converted to heat from the LED. This wasted heat burdens the LED driver and increases the complexity of the thermal design.

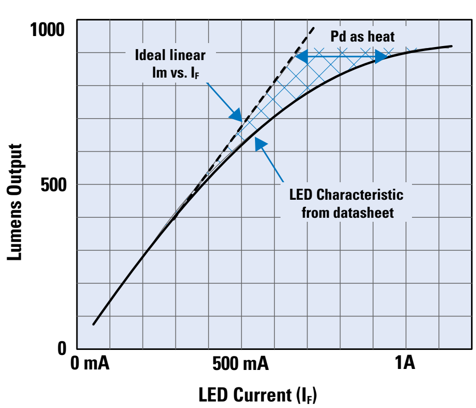


Figure 1. LED Output vs. LED Current

LED Color Temperature

Color temperature is a metric that describes the color of the LED and is quantified in LED datasheets. The color temperature of a given LED will be specified within a range and will shift with variances in forward current, junction temperature, and age. Lower color temperatures are more red-yellow (called warm) and higher-valued color temperatures are more blue-green (called cooler). Many colored LEDs will specify dominant wavelength instead of color temperature and are also subject to shift in wavelength.

LED Dimming Methods

Two popular methods for dimming LEDs in switched-mode driver circuits exist: Pulse-Width Modulation (PWM) dimming and analog dimming. Both methods control the time-averaged current through the LED or LED string, but there are differences between the two which become evident when examining the advantages and disadvantages of the two types of dimming circuits.

Figure 2 shows a switched-mode LED driver in a buck topology. V_{IN} must always be higher than the voltage across the LED + R_{SNS}. The inductor current is the LED current. The current is regulated by monitoring the voltage at the current sense or CS pin. As current sense or CS starts to fall below a set voltage, the duty cycle of the current pulses going through L1, the LED, and R_{SNS} increase, which increases the average LED current.

Analog Dimming

Analog dimming of LEDs is the adjustment of cycle-by-cycle LED current. More simply put, it is the adjustment of the constant LED current level. Analog dimming can be accomplished by an adjustment of the current sense resistor R_{SNS}, or by driving an analog voltage on some DIM function pin of the IC. ***Figure 2*** shows two examples of analog dimming.

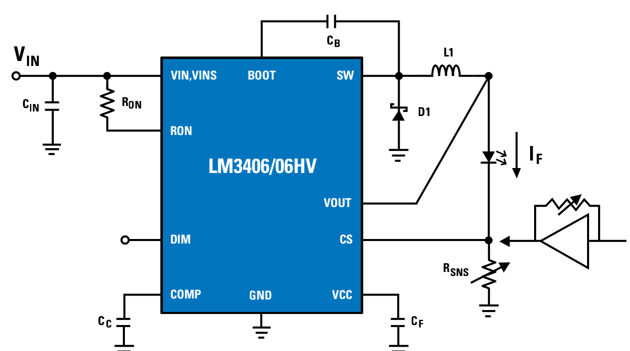


Figure 2. Buck Regulator Topology

Analog Dimming by Adjustment of R_{SNS}

It is clear from ***Figure 2*** that a change in value of R_{SNS} will correspond to a change in LED current with a fixed CS reference voltage. If one could find a potentiometer that could handle the high LED current and also was available in sub-1 Ohm values, this would be a viable method to dim the LED.

Analog Dimming by Driving DC Voltage on the CS Pin

More complex is a technique to directly control the cycle-by-cycle current of the LED by means of driving a voltage into the CS pin. The voltage source is typically inserted into a feedback loop where LED current is sampled and buffered by the amplifier ***(Figure 2)***. The LED current can be controlled by the gain of the amplifier. With this feedback circuitry, functionality such as current and thermal foldback can be implemented for further LED protection.

A disadvantage to analog dimming is that the color temperature of the emitted light can vary as a function of LED current. In situations where the color of the LEDs is critical, or the particular LED exhibits a large change in color temperature with changes in LED current, dimming the output of the LED by changing the LED current would be prohibitive.

PWM Dimming

The PWM method of dimming is the actual start and restart of the LED current for short periods of time. The frequency of this start-restart cycle must be faster than the human eye can detect to avoid a flickering effect, about 200 Hz or faster is usually acceptable.

The dimming of the LED now becomes proportional to the duty cycle of the dimming waveform, governed by the formula:

$$I_{DIM\text{-}LED} = D_{DIM} \times I_{LED}$$

where $I_{DIM\text{-}LED}$ is the average LED current, D_{DIM} is the duty cycle of the dim waveform, and I_{LED} is the nominal LED current setup with the selection of R_{SNS} as shown in ***Figure 3***.

Modulating the LED Driver

Many modern LED drivers feature a specialized PWM DIM pin that accepts a wide range of PWM frequencies and amplitudes, allowing a simple interface to external logic. The DIM function only shuts down the output drive while leaving the internal circuitry operating, avoiding the delay of restarting the IC. Output Enable pins and other logic shutdown functions can be used.

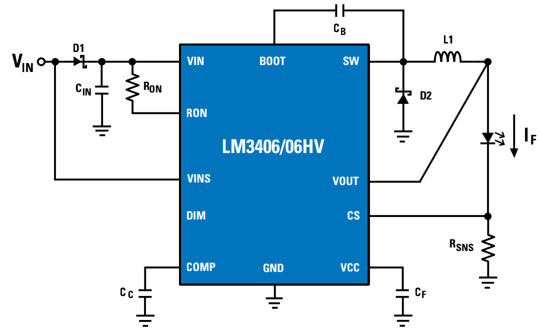


Figure 3. Two-Wire PWM Dimming

Two-Wire PWM Dimming

Two-wire PWM dimming is a popular method for automotive interior lighting. As V_{IN} is modulated below 70% of $V_{IN\text{-}NOMINAL}$, the VINS pin ***(Figure 3)*** detects the change in voltage and converts the PWM waveform into a corresponding PWM of the output drive. The disadvantage to this method is the power source to the converter must contain a circuit to provide a PWM waveform to its DC output.

Fast PWM Dimming with a Shunt Device

Because of the delays in shutdown and start up of the converter's output, there is a limit to the PWM dimming frequency and range of duty cycles. To help overcome this delay, an external shunt device such as the FET shown in Figure 4 can be placed parallel to the LED or LED string to quickly bypass the converter's output current around the LED(s).

The current in the inductor stays continuous during the "LED shutdown time," avoiding the long delay in ramping up and down the inductor current pedestal. The delay time now shifts to the limits of the shunt device's rise and fall times. ***Figure 4*** shows the LM3406 fitted with a shunt FET and a plot comparing the LED on/off delays between using the DIM function pin vs. the shunt FET. The output capacitance used in both of these measurements is 10 nf and the shunt FET is a Si3458.

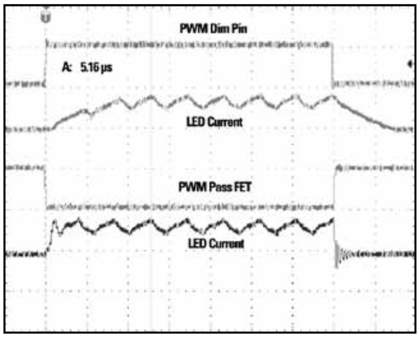


Figure 4. Circuit and PWM Waveforms

Designer's Corner

Caution should be used with shunting the LED current with current-mode converters because of the overshoot in output current when the FET turns on. The LM340x family of LED drivers are controlled on-time converters and will not exhibit this overshoot. Output capacitance across the LEDs should be kept low to maximize on/off/on transition speed.

A disadvantage to the fast-dim circuit vs. shutting down the outputs is loss of efficiency. While the shunt device is on, a power dissipation of $V_{SHUNT\ DEVICE}$ x I_{LED} is lost as heat. Use of low $R_{DS\text{-}ON}$ FETs will minimize this loss of efficiency.

LM3409 Multiple Dimming Functions

National Semiconductor's LM3409 is a unique LED driver in that it provides functionality for easy analog and PWM dimming. There are four possible ways to implement LED dimming on this part:

1. Analog dim by directly driving the I_{ADJ} pin with a voltage source from 0V to 1.24V
2. Analog dim by placing a potentiometer between I_{ADJ} pin and GND
3. PWM dim with the Enable pin
4. PWM dim by external shunt FETs

The LM3409 is wired for analog dimming by use of a potentiometer ***(Figure 5)***. Internal 5 µA current source creates a voltage across R_{ADJ}, which in turn varies the internal current sense threshold. The I_{ADJ} pin can be directly driven with a DC voltage for the same effect.

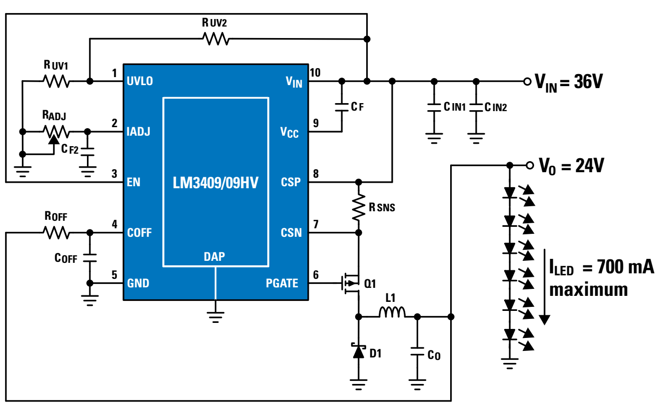


Figure 5. Analog Dimming Application

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Figure 6 shows a plot of measured LED current vs. the potentiometer resistance between the I_{ADJ} pin to GND. The flat-top at 1 Amp represents the maximum nominal LED current, set by the current sense resistor R_{SNS} shown in ***Figure 4***.

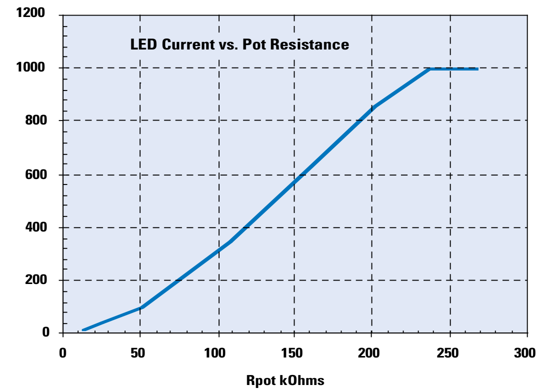

Figure 6. LED Current vs. Pot Resistance

Figure 7 shows the measured LED current as a function of driven DC voltage onto the I_{ADJ} pin. Notice the same maximum LED current set by R_{SNS}.

Both analog dimming options are easy to implement and provide very linear dim levels down to around 10% of maximum.

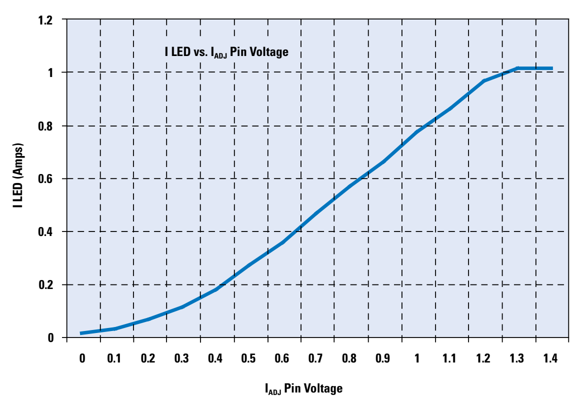

Figure 7. LED vs. I_{ADJ} Pin Voltage

Summary

There are many approaches to dimming LEDs powered by switched-mode regulators. The two main categories, PWM and analog, both have advantages and disadvantages. PWM dimming greatly reduces color changes in the LED with varying brightness levels at the expense of additional logic to create the PWM waveforms. Analog dimming can be a more simplistic circuit, but may be inappropriate for applications that require a constant color temperature.

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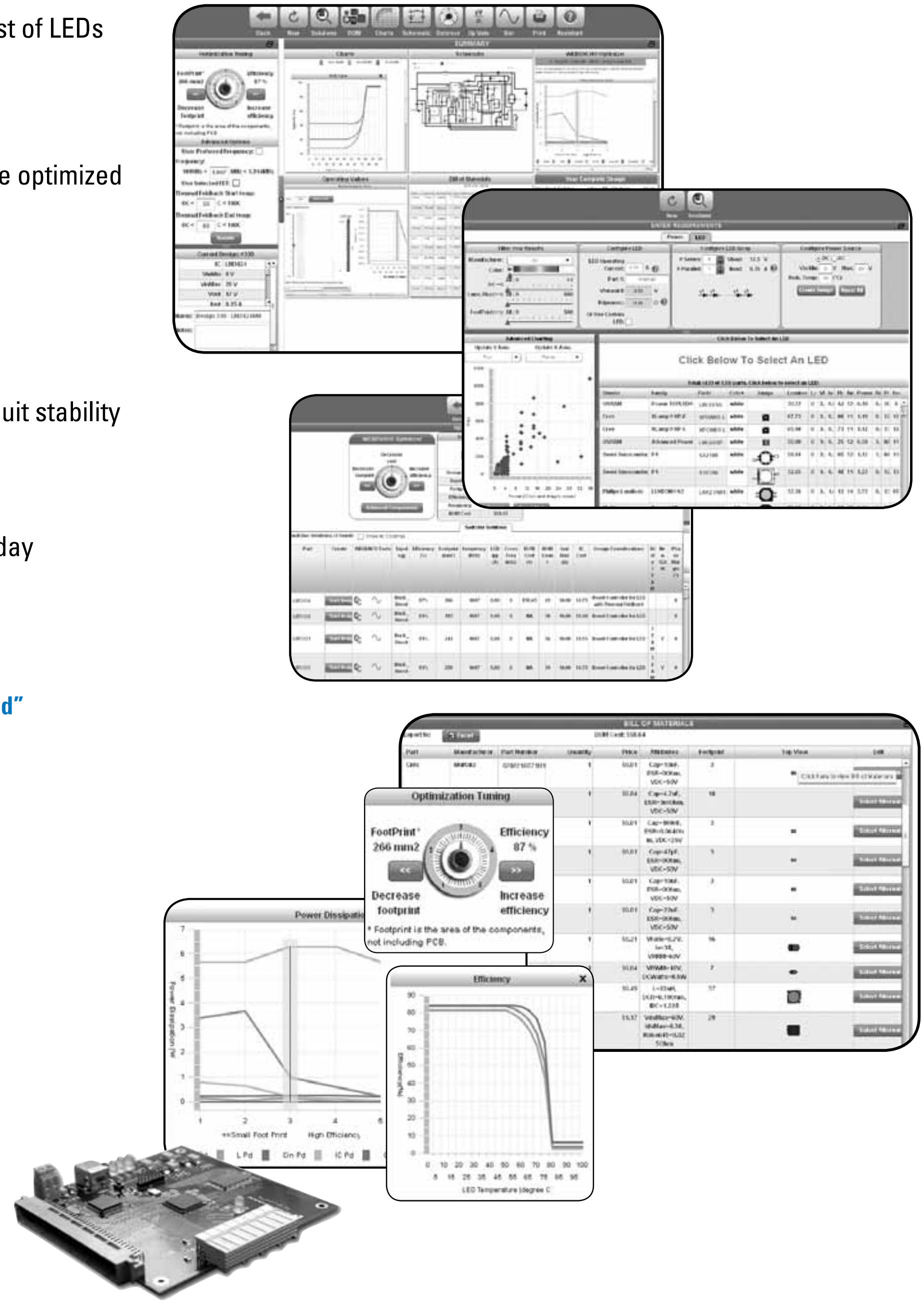

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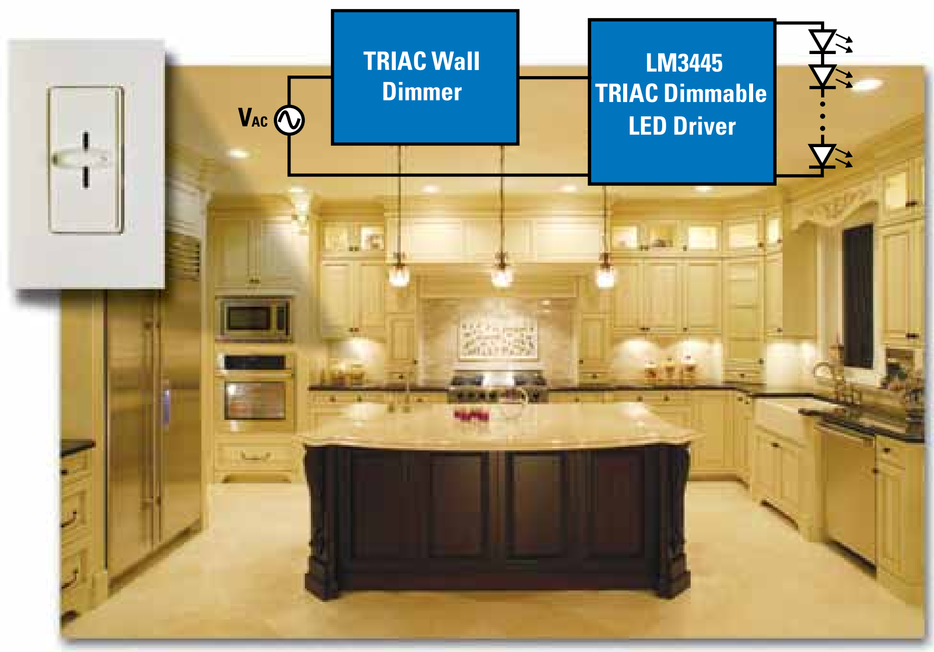

Full Range Dimming Capability

National's TRIAC dimmable LED driver offers 100:1 full range dimming capability, going from full light to nearly imperceptible light in a continuous range without being extinguished, and maintains a constant current to large strings of LEDs driven in series off of a standard line voltage.

Easy To Use

National's TRIAC dimmable LED driver enables a direct replacement of incandescent or halogen lamp systems that are currently interfaced to a TRIAC dimmer without having to change the original infrastructure or sacrifice performance. In addition, the new TRIAC dimmable LED driver is available in WEBENCH® LED Designer to allow for easy and quick design in.

Uniform Dimming Without Flicker

National's TRIAC dimmable LED driver allows master-slave operation control in multi-chip solutions which enables a single TRIAC dimmer to control multiple strings of LEDs with smooth consistent dimming, free of flicker.

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