

LED Drivers for High-Brightness Lighting

Solutions Guide

national.com/LED

2011 Vol. 1

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Energy-Efficient LED Driver Designs

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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

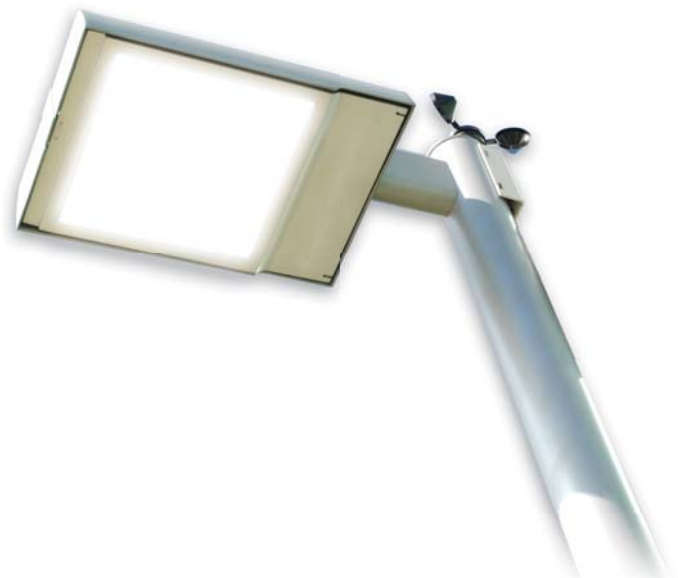
National's unique WEBENCH LED Designer online tool allows for quick and easy selection and simulation of a complete LED and LED driver solution. The tool provides lighting designers a competitive advantage and faster time to market. National's on-demand tools make it easy for designers to explore and 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



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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.

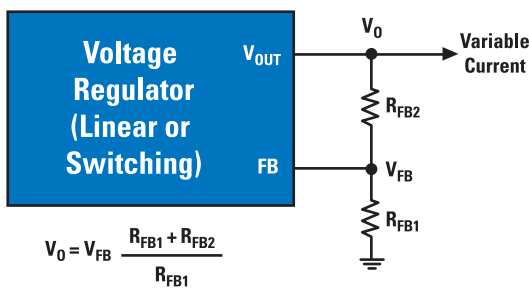
High-Brightness LEDs: Input Voltage and Forward Voltage

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 $12V \pm 10\%$.

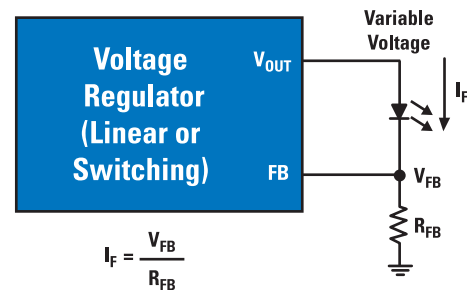
High-brightness (HB) LEDs also give a range of forward voltage. A typical HB LED might be characterized at a forward current of 350 mA. The forward voltage of the LED when $I_F = 350$ mA is specified with a range that includes a typical value as well as over-temperature maximum and minimum values. To 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



Constant Current Regulator



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 LEDs	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	
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	
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 LEDs	Multi-Output	Internal SWITCH	Topology	Key Features
LM3464/A ^{E, W} 	80 to 277	12 to 80/ 12 to 95	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
 LM3492 ^{E, W} 	4.5 to 65	Adjustable to 65	0.2	14 per ch	2 ch	✓	Boost	No loop compensation required, programmable LED current from 50 mA to 200 mA, 1000:1 contrast ratio at a dimming frequency of more than 3 kHz, minimum LED current pulse width is 300 ns, DHC maximizes efficiency

 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 LEDs	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 1.25V 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 LEDs	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 1.25V 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 LEDs	Multi-Output	Internal SWITCH	Topology	Key Features
^{NEW} LM3444 ^{E, W}	80 to 277	Adjustable	1+	1 to 14+	—	—	Floating Buck	Non-dimmable version of LM3445, adaptive programmable offline allows for constant ripple current, no 120/100 Hz flicker
LM3445 ^{E, W}	80 to 277	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
^{NEW} LM3450 ^{E, W}	80 to 277	Adjustable	1+	1 to 14+	—	—	Isolated Flyback	Active power factor correction, 70:1 PWM decoded from phase dimmer, analog dimming, digital angle and dimmer detection, dynamic holding current and smooth dimming transition

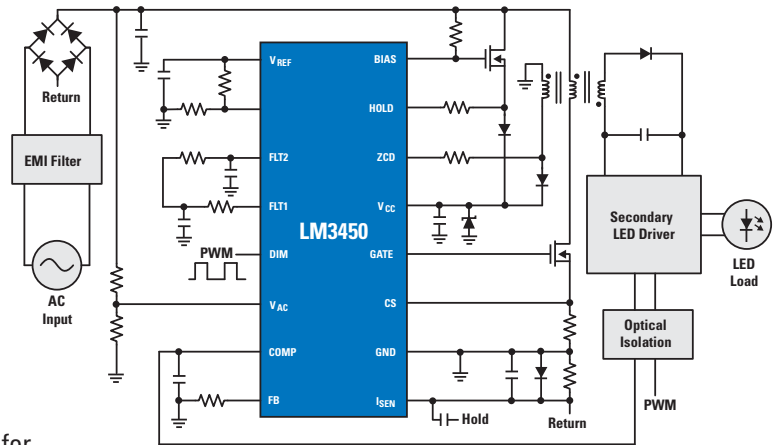
Note ⁽¹⁾ Specified in ISW PowerWise® product ^E Evaluation board ^W WEBENCH® enabled

Key Products Overview

LM3450 – LED Driver with Power Factor Correction and Phase-Dimming Decoder

Features

- Solution accepts universal line voltages
- Active power factor correction IC with phase-dimmer decoder
- Unique dynamic hold circuitry allows for high-performance, smooth dimming without flicker
- Compatible with both forward-phase (TRIAC) and reverse-phase dimmers
- 70:1 PWM decoded from phase dimmer
- Up to 100W output power
- Programmable dimming range
- Analog adjust pin allows for interface to sensors, thermal foldback, analog dimming, or dimmer range adjust
- Can be used in either single- or two-stage configurations for tradeoffs between solution size, efficiency, and noise immunity
- Over-voltage protection
- Feedback short-circuit protection
- Available in TSSOP-16 packaging



Applications

Ideal for use in phase-dimmable LED fixtures (10W to 100W output power)

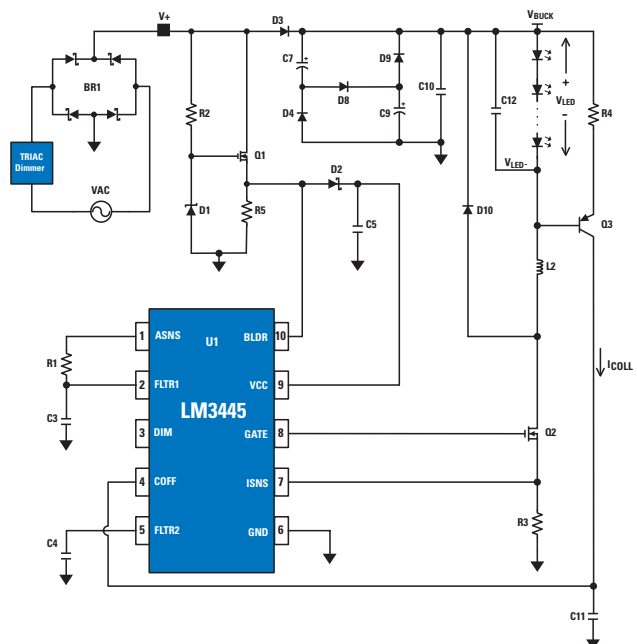
LM3445 – TRIAC-Dimmable LED Driver

Features

- Solution accepts universal line voltages
- Application voltage range from 80 VAC to 277 VAC
- Angle detector/decoder enables wide (100:1) full range dimming
- Integrated 300Ω bleeder resistor to ensure proper TRIAC signal decoding
- Patent-pending control architecture allows for constant ripple current which extends the life of the LEDs
- Scalable output current up to and greater than 1A
- Master/slave control for uniform dimming across multi-channel applications

Applications

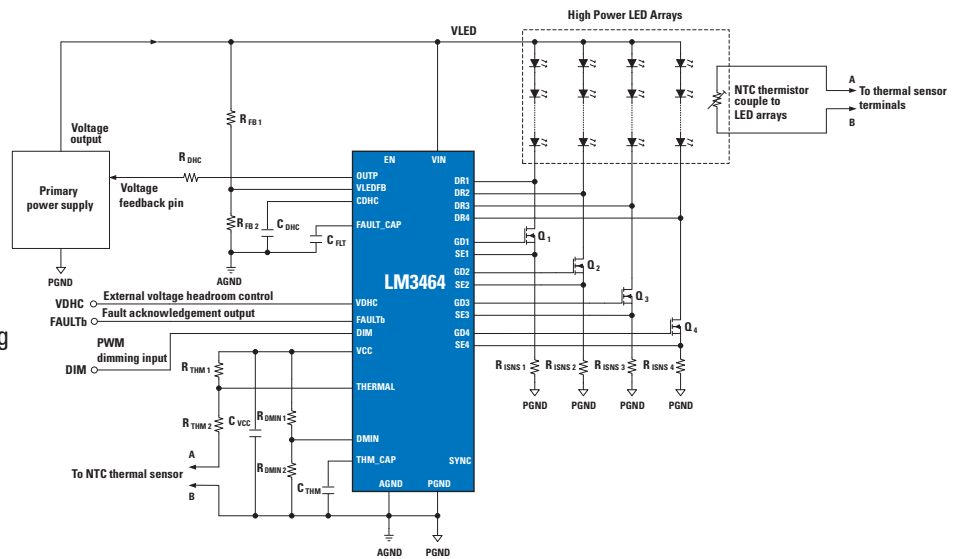
Ideal for use in LED bulbs up to 10W to 15W output power



LM3464 – LED Driver with Dynamic Headroom Control and Thermal Control Interfaces

Features

- Wide input voltage range (12V to 80V)
- Dynamic headroom control ensures maximum efficiency
- 4 output channels with individual current regulation
- High channel-to-channel accuracy
- Digital PWM/analog dimming control interface
- Resistor-programmable dimming frequency and minimum duty cycle (analog dimming mode)
- Direct interface to thermal sensor
- Fault detection
- Over-temperature protection
- Thermal shutdown
- Under-voltage lockout
- Available in thermally-enhanced eTSSOP-28 packaging



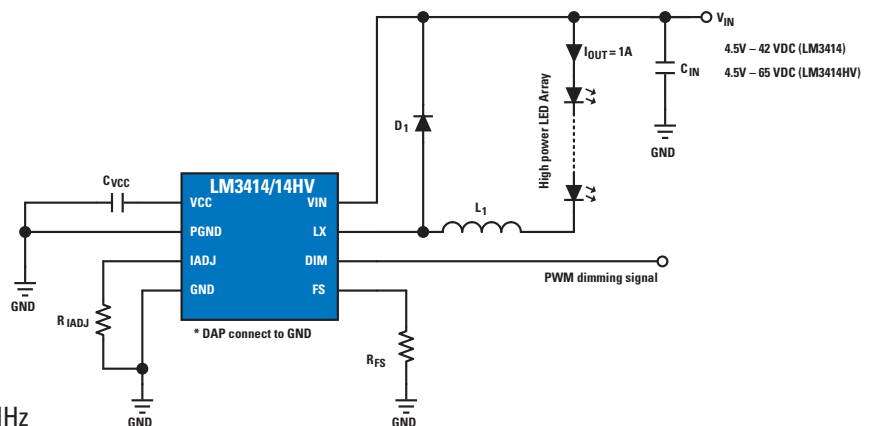
Applications

Ideal for use in high-power white applications such as street lamps, parking garage lamps, and warehouse lighting

LM3414 – 1A 60W Common-Mode-Capable Constant-Current Buck LED Driver

Features

- Wide input voltage ranges:
 - 4.5V to 42V (LM3414)
 - 4.5V to 65V (LM3414HV)
- Supports output powers up to 60W
- Adjustable LED current from 350 mA to 1A
- Analog and PWM dimming
- Thermal foldback
- Requires no external current sensing resistor
- ±3% LED current accuracy
- Up to 96% efficiency
- Integrated low-side N-channel MOSFET
- Switching frequency adjustable from 250 kHz to 1 MHz
- Thermal shutdown protection
- Available in power-enhanced ePSOP-8 or LLP-8 (3 mm x 3 mm) packaging



Applications

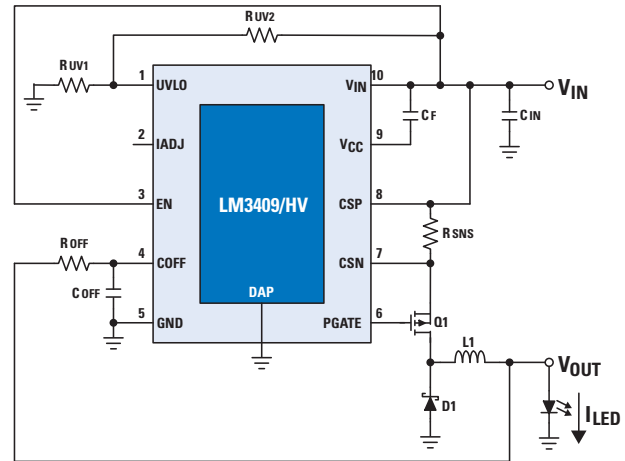
Ideal for use in space-constrained general illumination applications, MR16 replacement lamps, and LED fixtures

Key Products Overview

LM3409 – PFET Buck Controller for High-Power LED Drivers

Features

- 2.0Ω MOSFET gate drive
- V_{IN} range 6V to 42V (LM3409)
- V_{IN} range 6V to 75V (LM3409HV)
- Differential, high-side current sensing
- No control-loop compensation required
- Cycle-by-cycle current limit
- 10,000:1 PWM dimming range
- 250:1 analog dimming range
- Low power shutdown
- Supports all-ceramic output capacitors and capacitor-less outputs
- Thermal shutdown protection
- Available in thermally-enhanced eMSOP-10 packaging



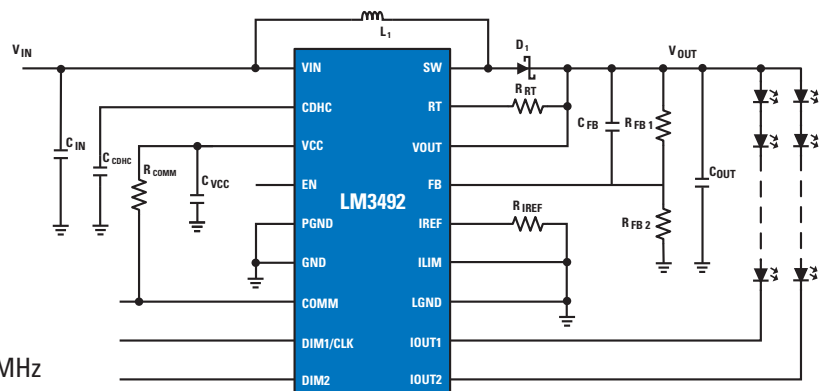
Applications

Ideal for use in LED drivers, constant-current sources, automotive lighting, general illumination, and industrial lighting

LM3492 – Two-Channel Individual Dimmable LED Driver with Boost Converter and Fast Current Regulator

Features

- 4.5V to 65V input voltage range
- Two individual dimmable LED strings up to 65V
- Programmable LED current from 50 mA to 200 mA
- Dynamic headroom control maximizes efficiency
- 1000:1 contrast ratio at a dimming frequency of more than 3 kHz
- Programmable soft-start
- No loop compensation required
- Stable with ceramic and other low-ESR capacitors with no audible noise
- Switching frequency programmable from 200 kHz to 1 MHz
- Over-power protection
- $\pm 3\%$ current accuracy
- Precision enable
- COMM I/O pin for diagnostic and commands
- Thermal shutdown protection
- AEC-Q100 grade 1 qualified
- Available in thermally-enhanced eTSSOP-20 packaging



Applications

Ideal for use in ultra-high contrast ratio 6.5" to 10" LCD display backlight up to 28 LEDs and automotive or marine GPS displays

High-Brightness LED Applications

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

Features

- PowerWise® energy-efficient solutions
 - Providing the best power-to-performance ratios
 - Enabling reliable and robust solutions
- Cutting-edge features including dimming, thermal management, fault protection, and more
- Low external component count and small solution sizes
- Easy-to-use tools and resources:
 - WEBENCH® LED Designer
 - Reference designs
 - Application notes

Applications

LED Driver	LED Bulbs	Outdoor High-Power Wide Area	Down Lights	Automotive	Display Backlighting	Medical	Entertainment	Portable Consumer	Portable Projectors
LM3401		✓		✓		✓	✓	✓	
LM3402/HV		✓		✓		✓	✓		
LM3404/HV		✓		✓		✓	✓		
LM3405/A		✓		✓		✓		✓	
LM3406/HV		✓		✓		✓	✓		
LM3407		✓		✓		✓		✓	
LM3409/HV		✓	✓	✓		✓	✓	✓	
LM3410		✓		✓	✓	✓		✓	
LM3414/HV		✓	✓	✓		✓	✓		
LM3421/23		✓	✓	✓		✓	✓		✓
LM3424		✓	✓	✓	✓	✓	✓		✓
LM3429		✓	✓	✓		✓	✓		✓
LM3430/32					✓				
LM3431				✓	✓	✓			
LM3433						✓	✓		✓
LM3434						✓	✓		✓
LM3444	✓		✓			✓			
LM3445	✓		✓						
LM3450	✓		✓						
LM3464		✓							
LM3492				✓	✓	✓			

High-Brightness LED Applications

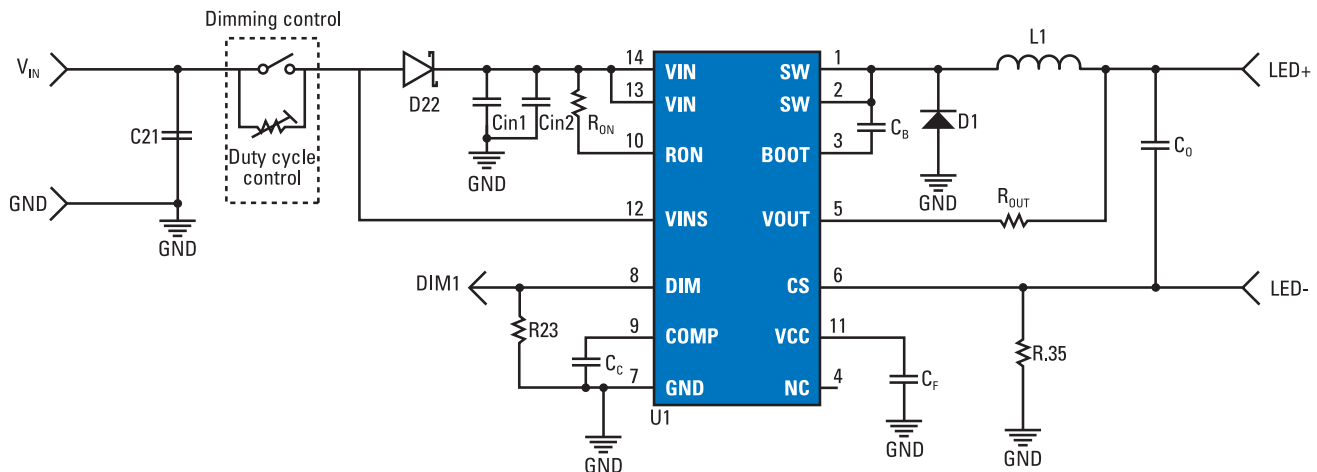
Two-Wire Dimming

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.



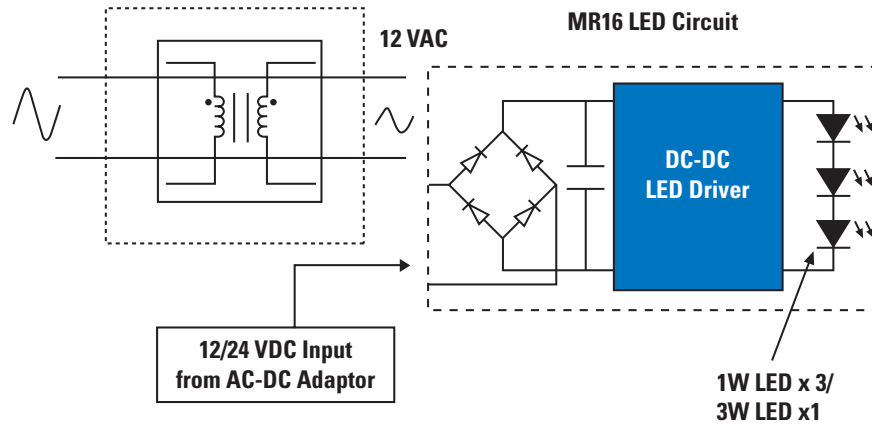
The benefit of two-wire dimming: One wire less than traditional PWM dimming, further reducing the wiring cost

High-Brightness LED Applications

LED Bulbs

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

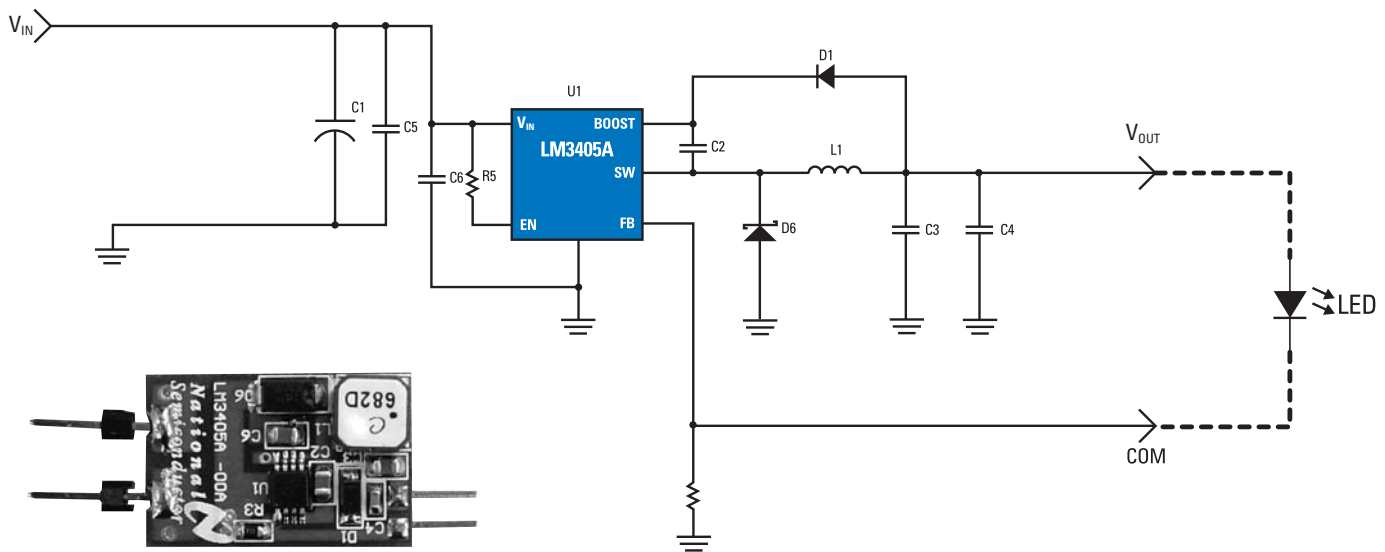
High-Brightness LED Applications

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 and Current

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

2: Efficiency

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

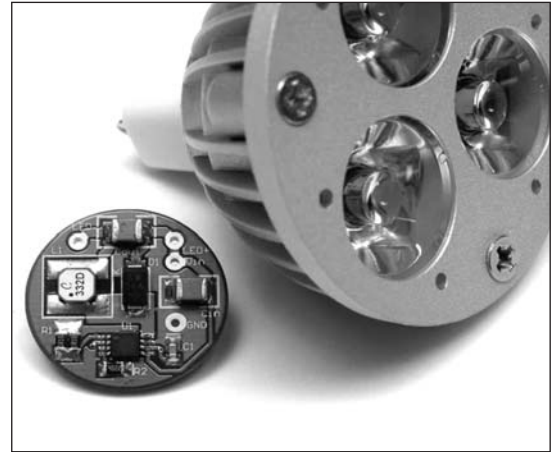
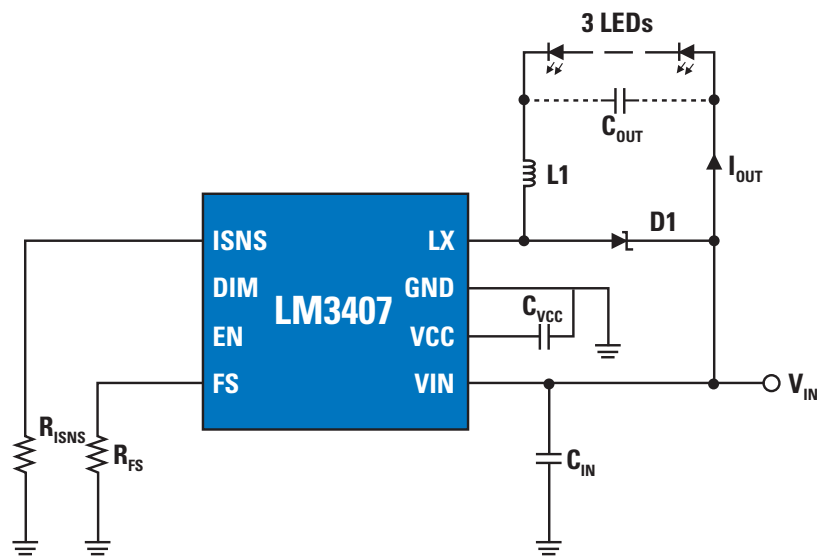
BOM (Main Components)

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 and Current

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

2: Efficiency

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

BOM (Main Components)

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

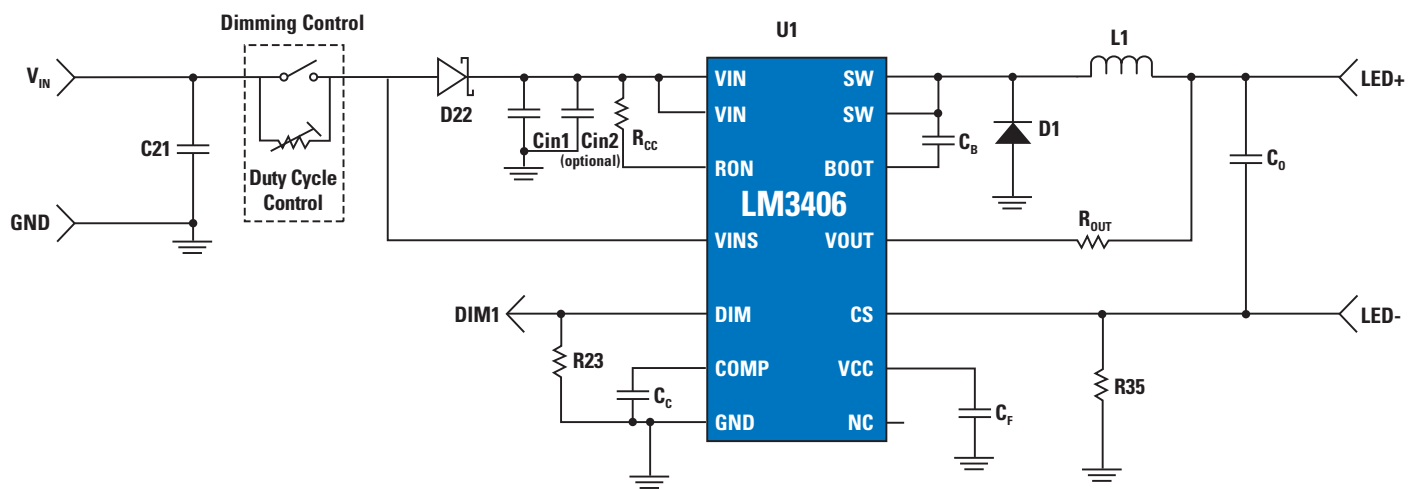
High-Brightness LED Applications

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} (VDC)	Load	V_{OUT} (V)	I_{LED} (A)
12	2 LEDs	4.20	1.50

2: Efficiency

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

BOM (Main Components)

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

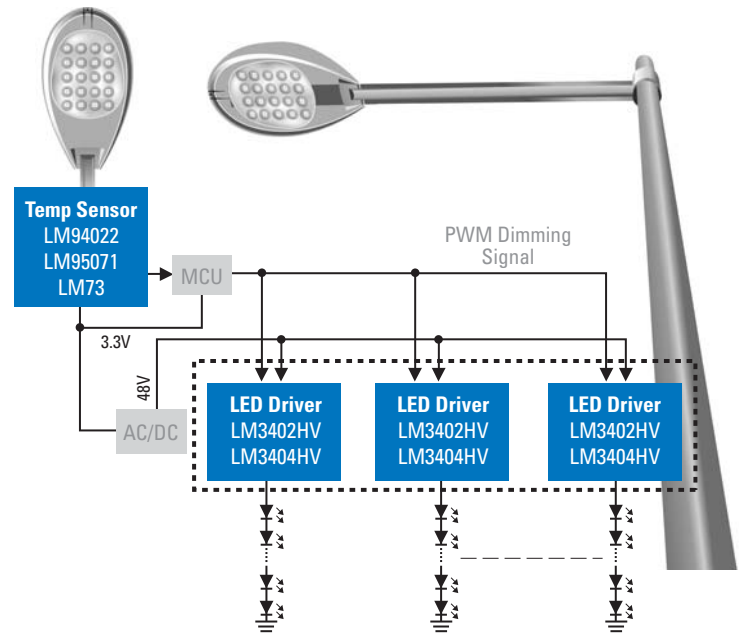
High-Brightness LED Applications

Outdoor High-Power Wide Area

48V Bus Street Lamp

Key Benefits of LM3402/04/06HV 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



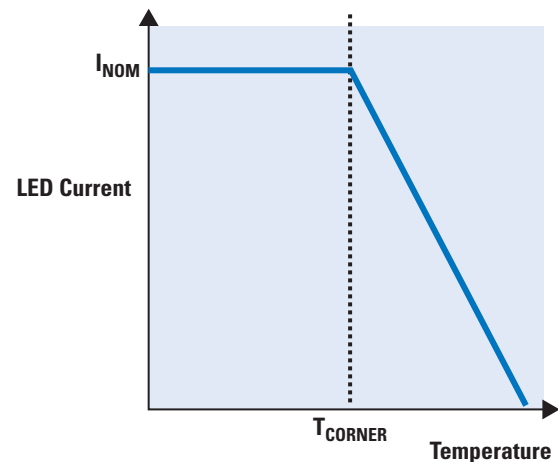
LED Street Lamp Architecture

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 (T_{corner}) 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.



High-Brightness LED Applications

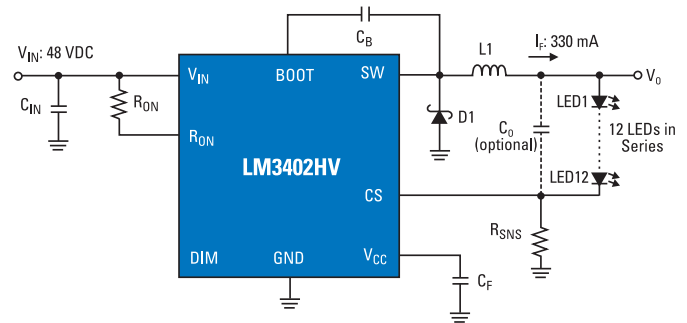
Outdoor High-Power Wide Area

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 and Current

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

2: Efficiency

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

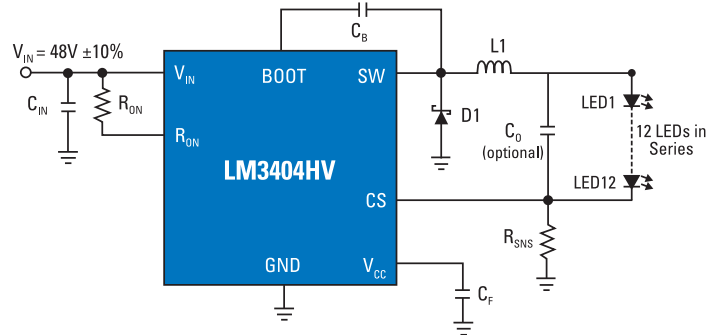
BOM (Main Components)

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 μ H, 1.9A, 0.56 Ω	DO5022P-334	Coilcraft
3	Cin	2.2 μ F/100V/1812	C4532X7R2A225M	TDK
4	Co	0.15 μ F, 100V, 1206	C3216X7R2A154M	TDK

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 and Current

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

2: Efficiency

Input Voltage (V)	Reading				
	V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{LED} (A)	Efficiency
52	51.97	0.847	41.975	1.017	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 μ H, 0.229 Ω , 2.2A	MSS1278-184KL	Coilcraft
3	Cin	2.2 μ F/100V/1812	C4532X7R2A225M	TDK
4	Co	0.15 μ F, 100V, 1206	C3216X7R2A154M	TDK

High-Brightness LED Applications

Outdoor High-Power Wide Area

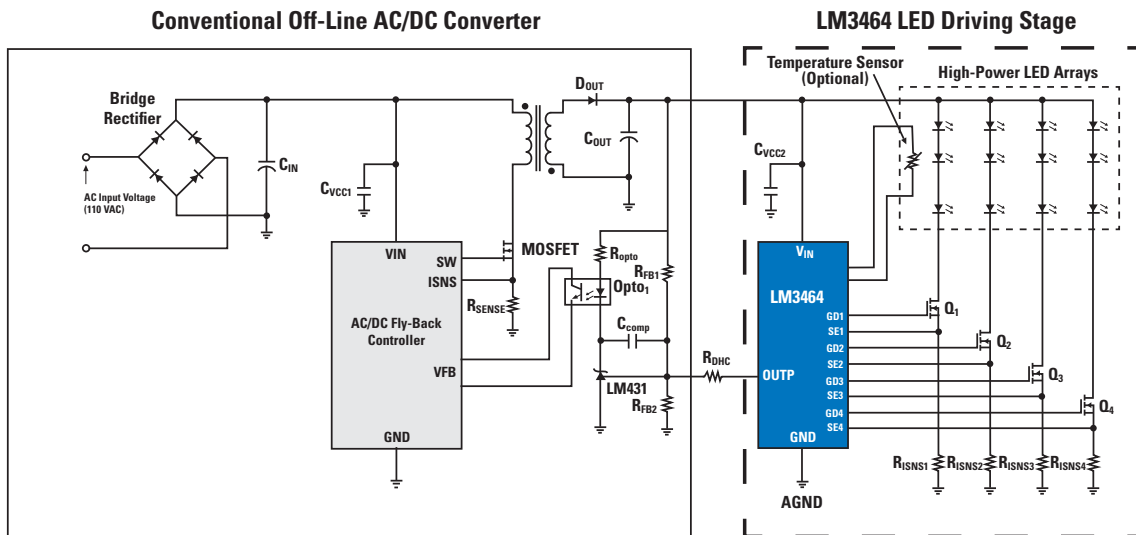
Design 3: Key Benefits of LM3464 in Street Lamp Design

Description:

- Wide input voltage range
 - 12V to 95V (LM3464A)
 - 12V to 80V (LM3464)
- Dynamic Headroom Control (DHC)
 - Automatic efficiency optimization (over 98%)
- Thermal foldback control
 - Output power reduction under high-operation temperature
 - Accepts analog-dimming control signal
- Four individually-regulated current outputs
 - High-accuracy LED current regulation
 - External resistor-programmable output current
- Requires no magnetic component (inductor)
 - No cross interference among output channels
 - Eases EMC filter design
- Integrated failure protection and handling circuit
 - Four individual output failure-detection circuits
 - Prevents substantial damage due to LED failures
- Simple interface to common AC/DC converter circuits

Electrical Characteristics:

- Input voltage: 110 VAC/60 Hz
- Output rail voltage (max.): 39 VDC
- Output current (per ch.): 350 mA
- No. of LEDs (per ch.): 12
- LED power: 53.3W
- AC/DC converter efficiency: 83.8%
- System efficiency with LM3464: 82.2%
- LM3464 driver stage efficiency: 98.1%



General Structure of the LM3464 Illumination System

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.

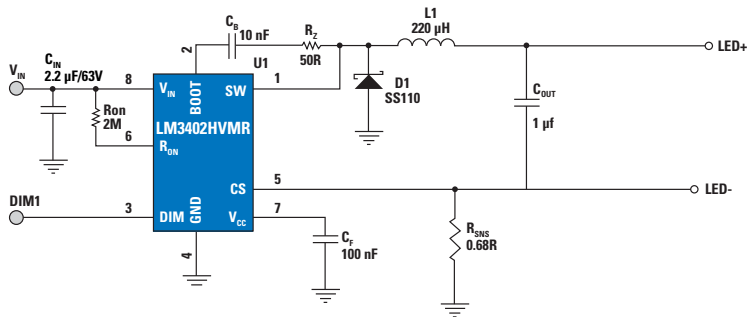


Figure 1

The modifications are:

- 1: One resistor R_z (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 R_z selection is dependent on the SW turn-on slew rate and its ringing. The smaller the ringing, the better.
- 2: 1 μ F 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.

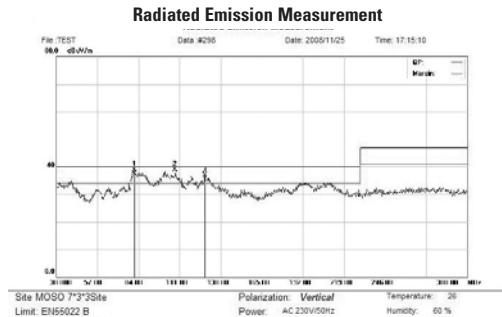


Figure 2

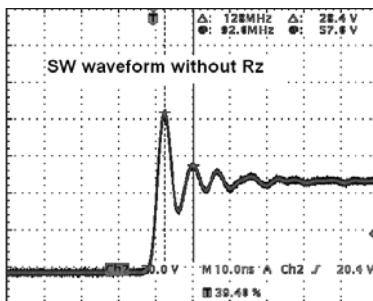


Figure 3

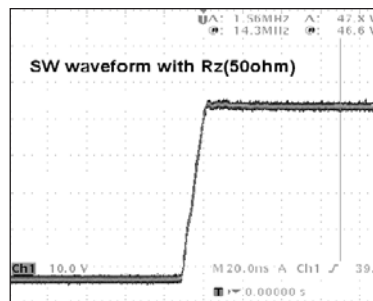


Figure 4

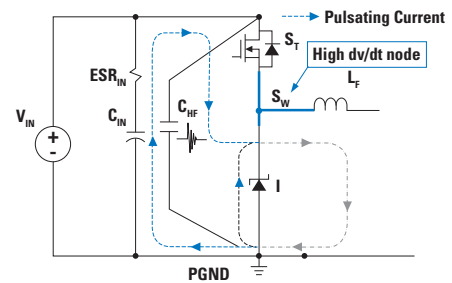


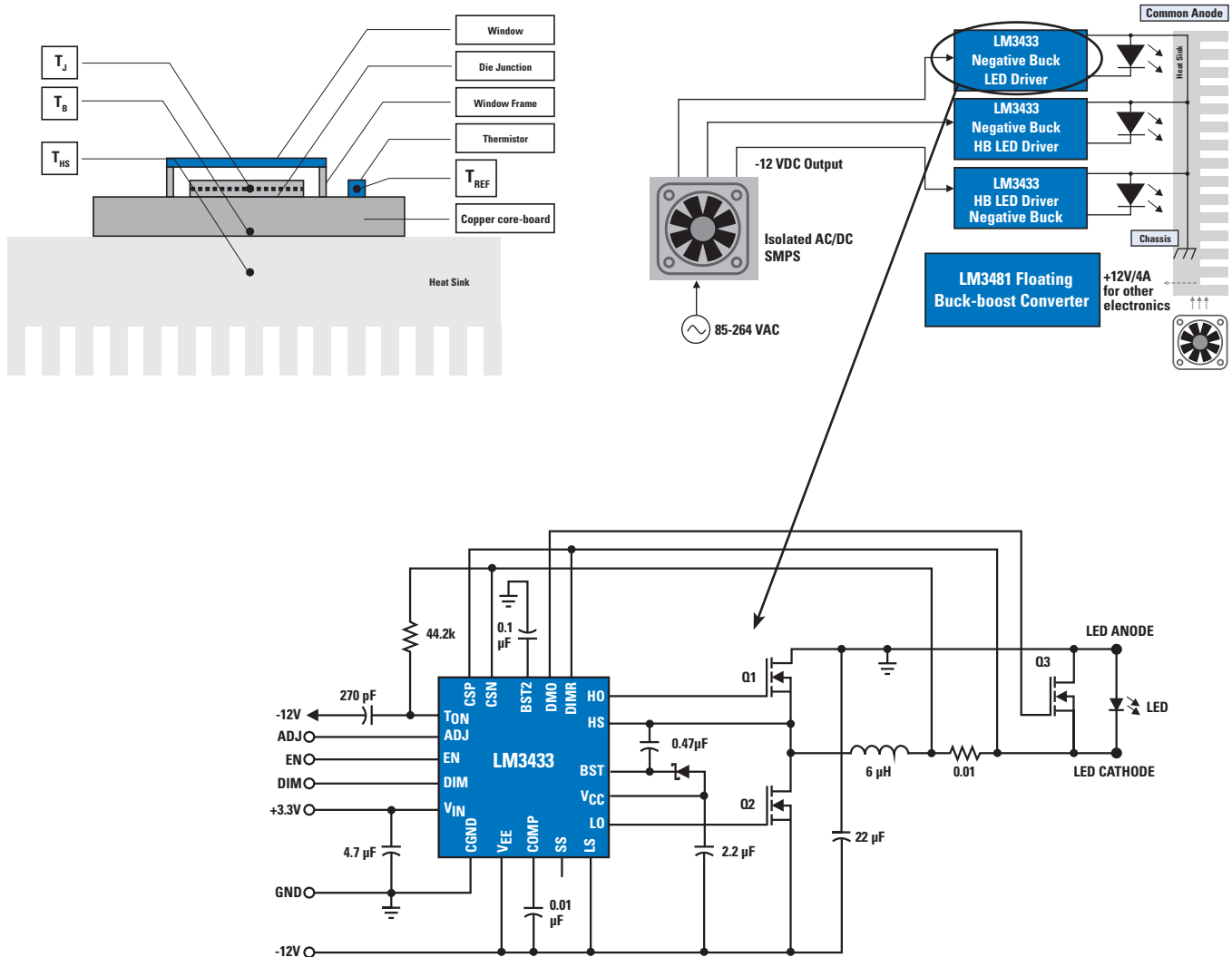
Figure 5

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.

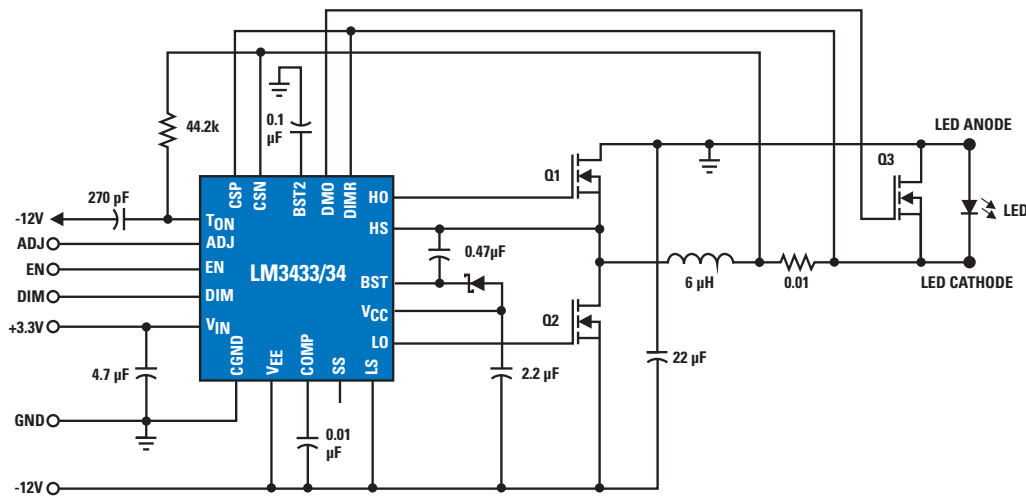


LED Projector Using LM3433/34

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} (VDC)	Load	V_{OUT} (V)	I_{LED} (A)
-12	1 LED	4.60	6

2: Efficiency

		Reading			
Input Voltage (V)	V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{LED} (A)	Efficiency
-12	-12	2.47	-4.60	6	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 μ H, 14A	GA3252-AL	Coilcraft
3	C3	150 μ F, 16V	16SA150M	MULTICAP
4	C4	1210 22 μ F x 2, 16V	GRM32ER61C226KE20L	Murata
5	C6	1210 47 μ F, 16V	GRM32ER61C476ME15L	Murata
6	MOSFET (Q1,Q2,Q3,Q4)	PowerPAK 30V, 9.5 m Ω	Si7386DP	Vishay
7	LED	6A	PT39	Luminus

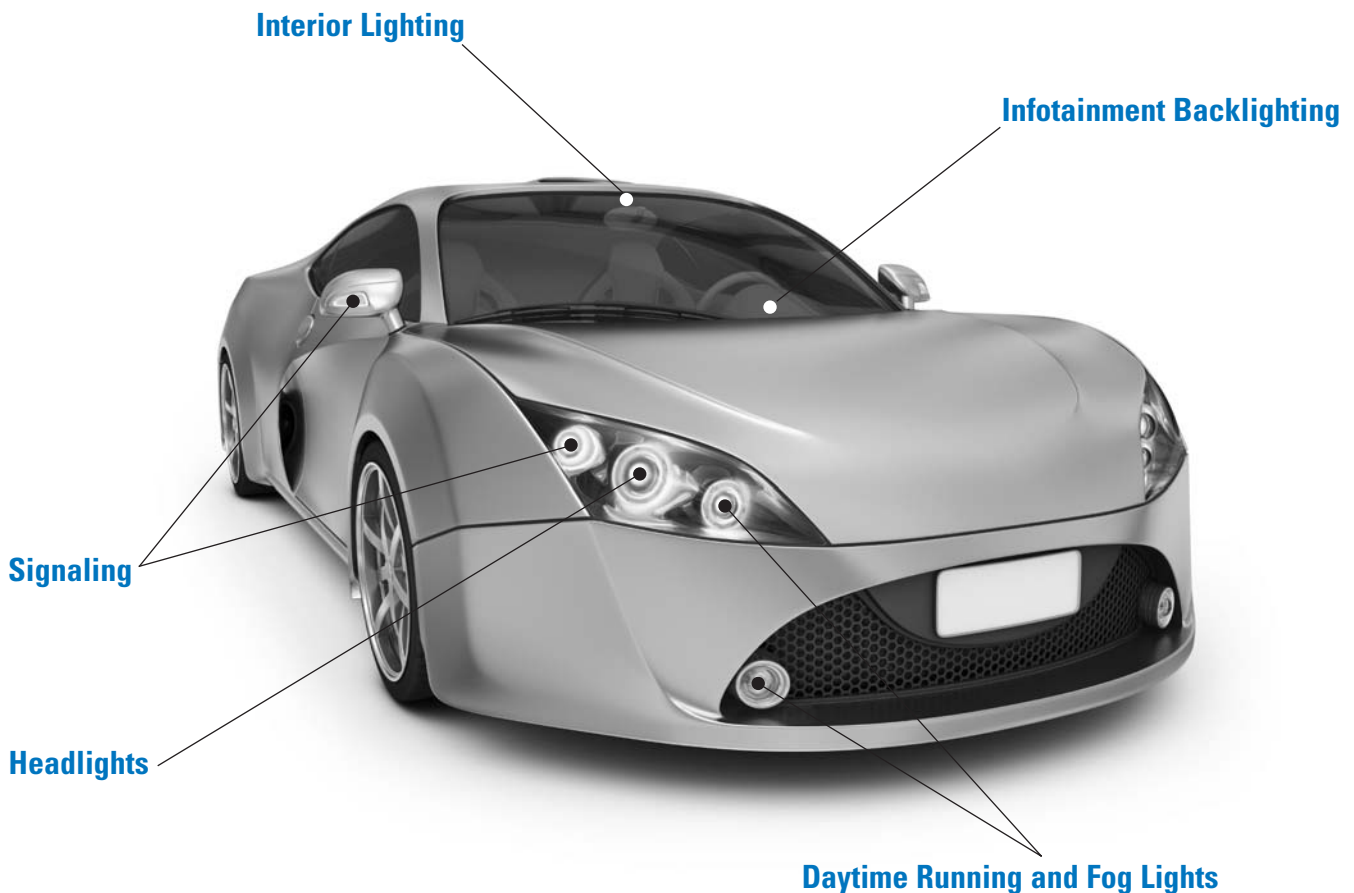
High-Brightness LED Applications

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.

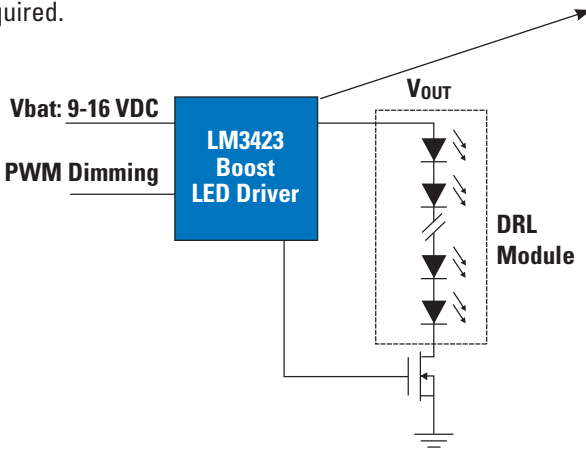
Features	Benefits
High efficiency	Better thermal management
High-side current sensing	LEDs grounded to chassis for better thermal dissipation
Accurate current control	Extends LED lifetime
PWM and analog dimming	Easily reduces current when battery is low to avoid excessive battery drain
Wide voltage range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



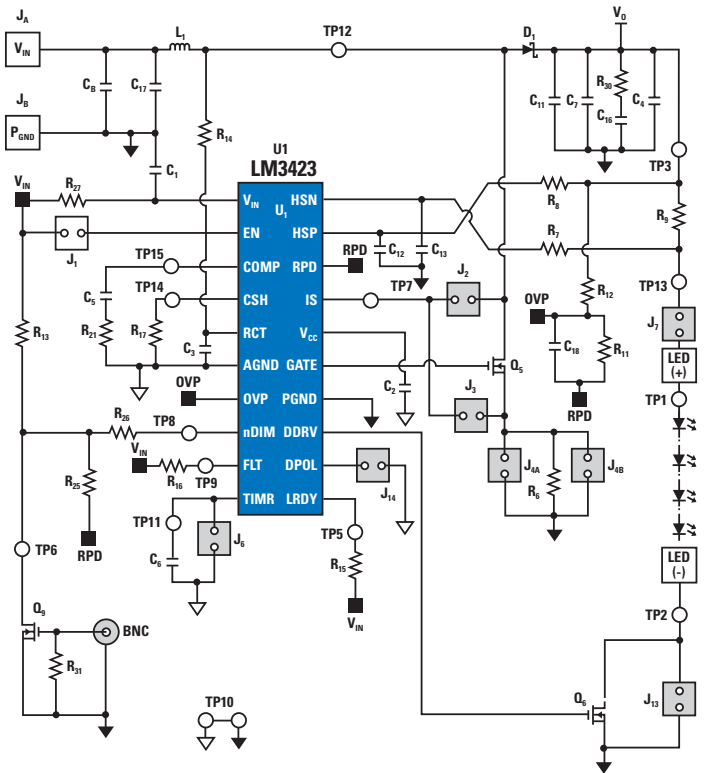
Design 1: Driving Daytime Running Lamp (DRL) with LM3423 Boost LED Driver

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 and Current

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

2: Efficiency

Reading					
Input Voltage (V)	V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{LED} (A)	Efficiency
12	12	1.65	46	0.40	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

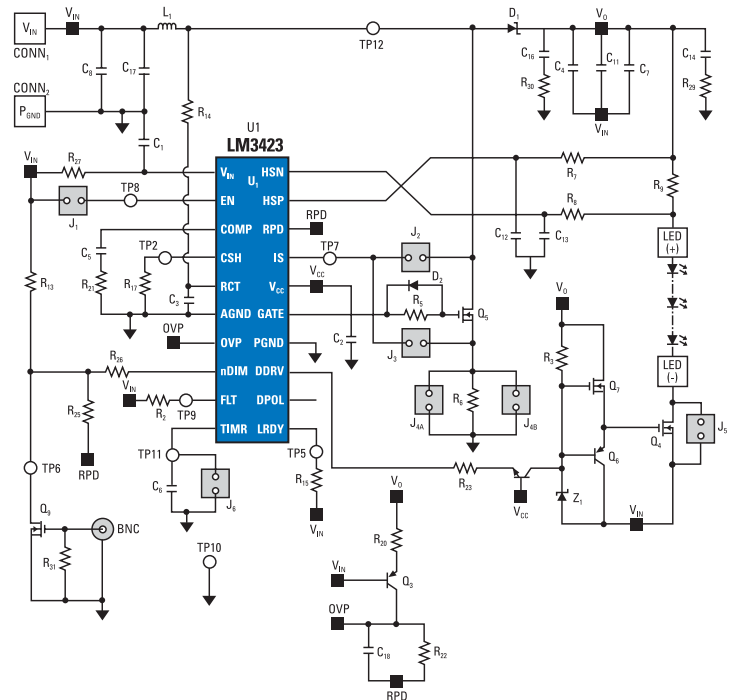
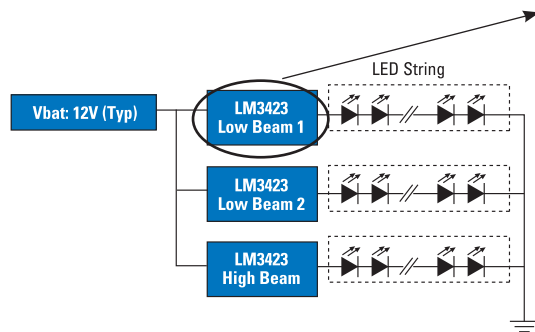
High-Brightness LED Applications

Automotive Lighting

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 and Current

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

2: Efficiency

		Reading			
Input Voltage (V)	V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{LED} (A)	Efficiency
12	12	1.87	20	1	88.98%
24	24	0.93	20	1	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 μ H	DO5040H	Coilcraft
3	C8 (Cin)	330 μ F/35V 5 mm Lead	ECA-1VM331	Panasonic
4	C7 (Cout1)	330 μ F/35V 5 mm Lead	ECA-1VM331	Panasonic
5	C11 (Cout2)	1210 10 μ F, 25V	ECJ-4YB1E106M	Panasonic

Design 3: LED Backlighting Applications Using LM3431

LED Backlighting Infotainment



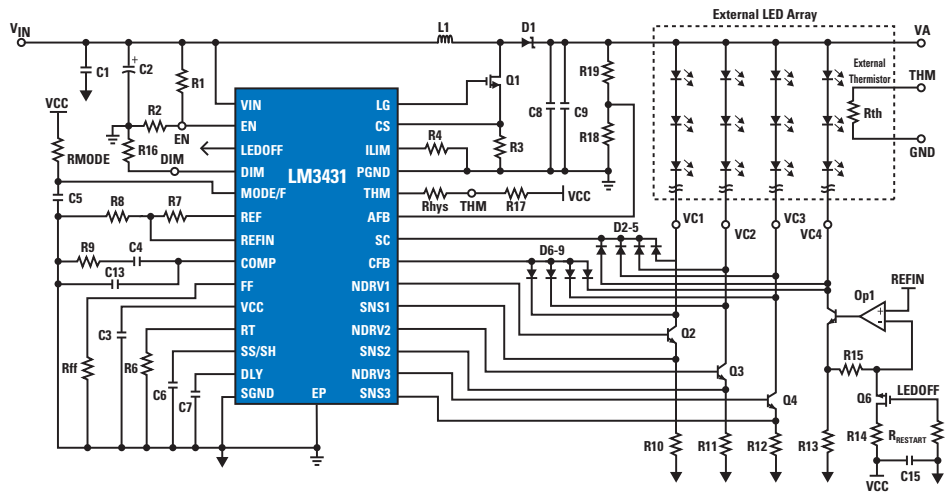
LED Backlighting for Dashboards



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 and Current

Parameter		Reading	
V_{IN} (VDC)	Load	V_{OUT} (V)	I_{LED} (A)
8 to 18	4 strings of 8 LEDs, V_f : 3.2V	25.60	0.14

2: Efficiency

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

BOM (Main Component)

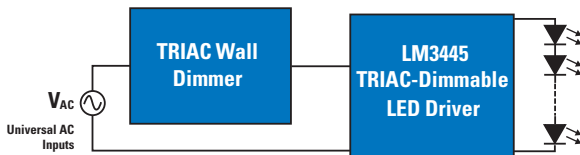
Item	Designation	Description	Part No.	Vendor
1	U1	Boost controller for multi-channel constant-current LED drivers	LM3431 (eTSSOP-28)	National
2	L1	7 μ H 3.1A inductor	MSS1038-702NL	Coilcraft
3	C2 (Cin_1)	10 μ F 50V electrolytic	UUD1H100MCL	Nichicon
4	C1 (Cin_2)	1 μ F 50V B ceramic	GRM32RB11H105KA01	Murata
5	C3 & C8 (Cout)	2 x 4.7 μ F 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 and Current

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

2: Efficiency

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

BOM (Main Components)

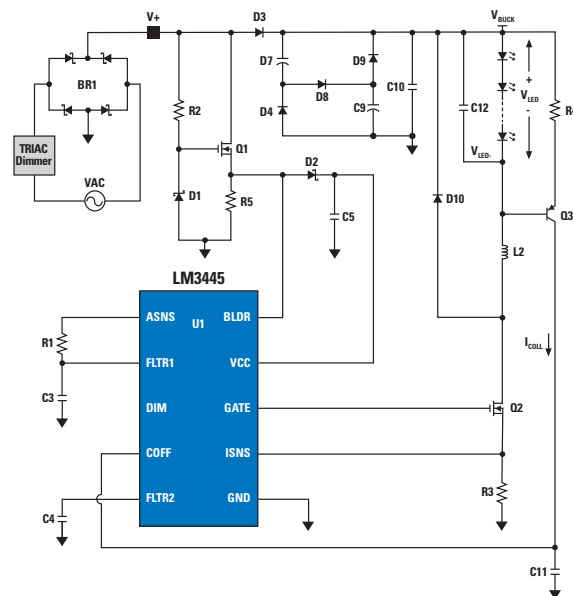
Item	Designation	Description	Part No.	Vendor
1	U1	LED driver controller	LM3445MM (mini SOIC-10)	National
2	BR1	Bridge rectifier, SMT, 400V, 800 mA	HD04-T	Diode
3	L2	Inductor, SHLD, SMT, 1A, 470 μ H	MSS1260-474KLB	Coilcraft
4	C7, C9	Cap, AL, 200V, 105C, 20%, 33 μ F	EKXG201ELL330MK15L	UCC
5	D4, D9	Diode, 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

TRIAC-Dimmable LED Lamp with LM3445

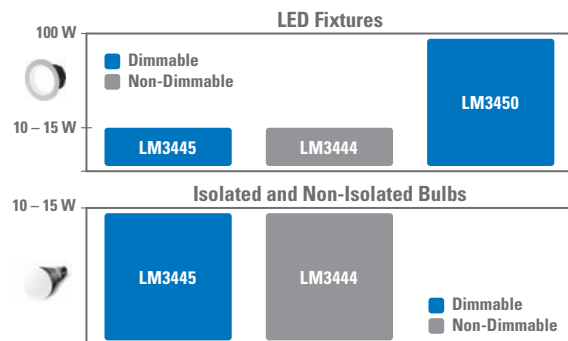
Description:

- 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



Phase-Dimmable LED Drivers



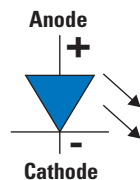
fixture image courtesy of Cree

Light Matters: The ABC's of LEDs

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. **Note: Please read parts 1-4 in full at national.com/led under the Apps tab.**

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

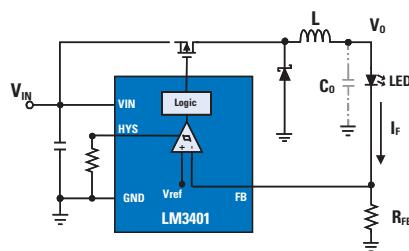


Many characteristics make buck-based regulators attractive LED drivers. They are simple to configure as a current source and can be realized with minimum component counts, which simplifies the design process, improves the drivers' reliability, and reduces cost. Buck-based LED drivers also provide configuration 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.

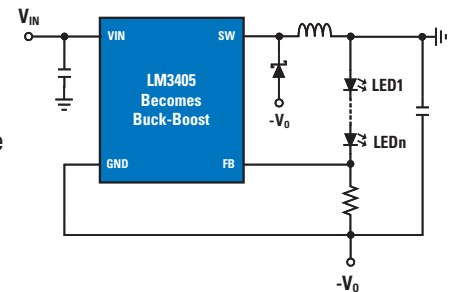


The total forward voltage drop of an LED string is equal to the sum of the forward voltage drops of all the LEDs in the string. In some cases, the input voltage range of the system can be lower than the forward voltage drop of the LED string, or it can vary so that sometimes it's lower and sometimes 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...](#)

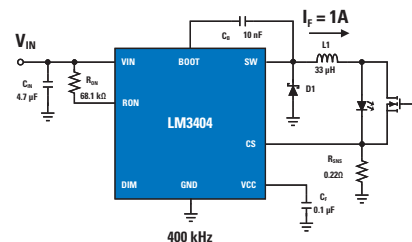
- Challenges of Boost and Buck-Boost
- Other Topologies

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.

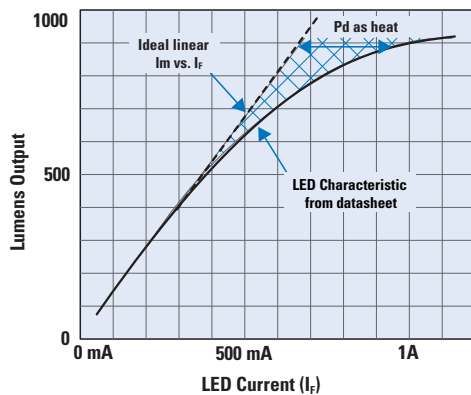


Figure 1. LED Output vs. LED Current

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.

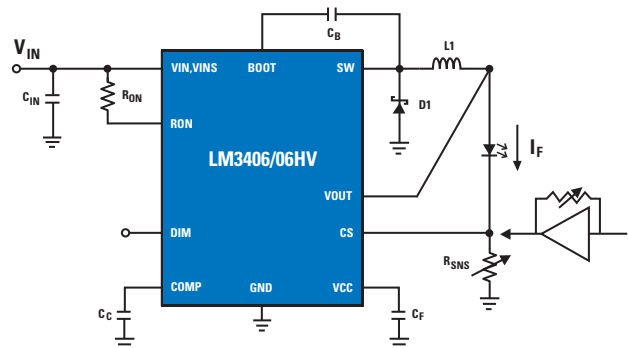


Figure 2. Buck Regulator Topology

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. As shown in **Figure 2**, the voltage source is typically inserted into a feedback loop where LED current is sampled and buffered by the amplifier. 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:

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

where $I_{DIM-LED}$ 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.

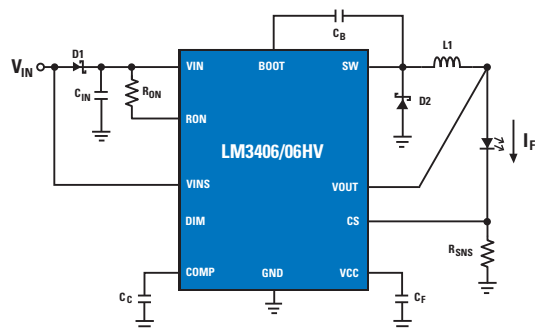


Figure 3. Two-Wire PWM Dimming

Two-Wire PWM Dimming

Two-wire PWM dimming is a popular method for automotive interior lighting. As V_{IN} is modulated below 70% of $V_{IN-NOMINAL}$, the VINS pin detects the change in voltage and converts the PWM waveform into a corresponding PWM of the output drive as seen in **Figure 3**. 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 startup 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.

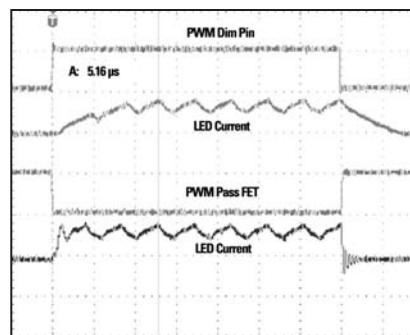


Figure 4. Circuit and PWM Waveforms

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 $V_{SHUNT DEVICE} \times I_{LED}$ is lost as heat. Use of low R_{DS-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 as shown in **Figure 5**. Internal 5 μ A 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.

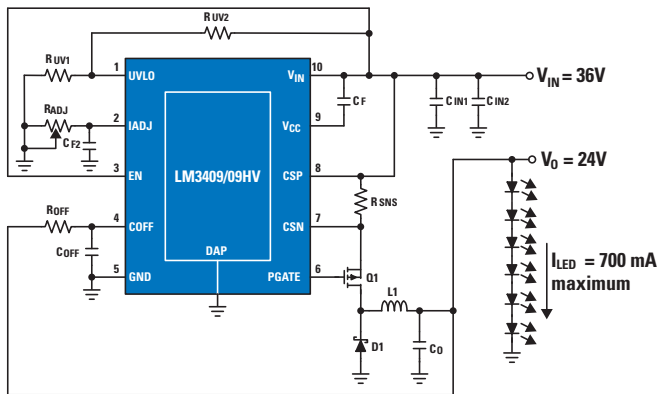


Figure 5. Analog Dimming Application

For an online version, visit: national.com/powerdesigner

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**.

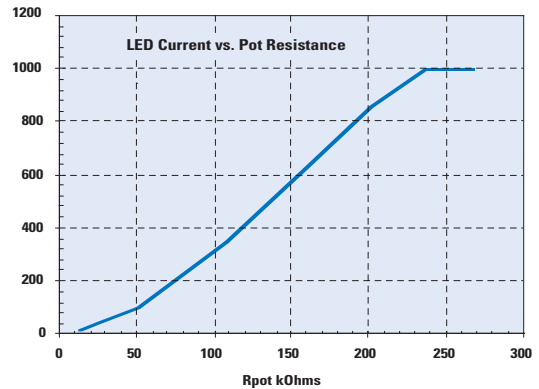


Figure 6. LED Current vs. Pot Resistance

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.

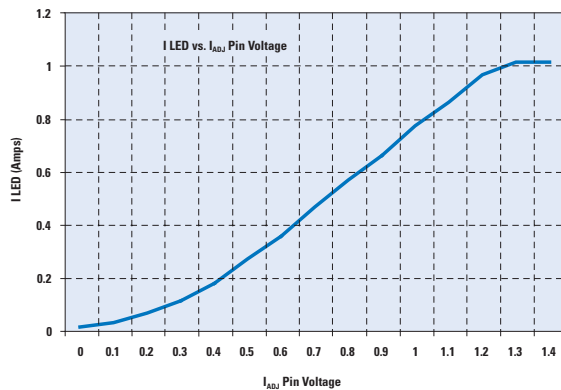


Figure 7. LED vs. I_{ADJ} Pin Voltage

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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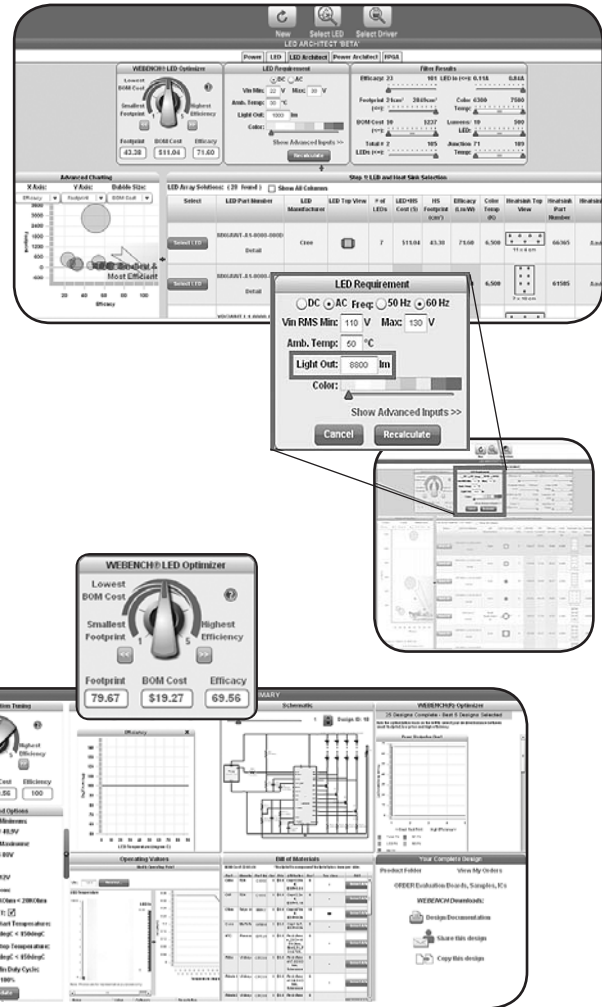
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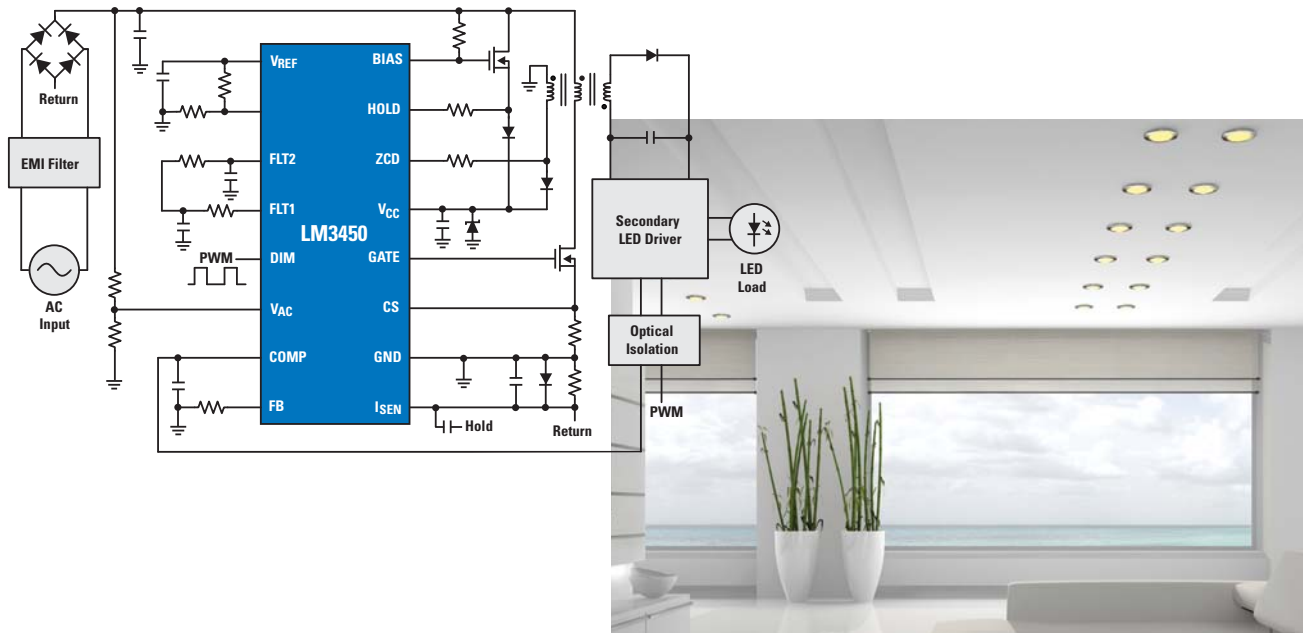
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High Performance Delivers Flicker-Free Illumination.

LM3450 LED driver integrates power factor correction and phase dimming decoding for flicker-free, uniform dimming.

National's LM3450 phase dimmable LED driver integrates active power factor correction and a phase dimming decoder, making it ideal for 10W-100W phase dimmable LED fixtures. It accepts universal input voltages, features unique dynamic hold circuitry for excellent dimming performance, and an analog adjust pin for differentiated features such as thermal foldback, interface to sensors, or dimmer range adjust.



High Performance

The LM3450 LED driver integrates a phase dimming decoder and unique dynamic hold circuitry to enable higher performance dimming without flicker and higher efficiency during dimming. It enables smooth, consistent LED dimming over a wide dim range without flicker even at low dim levels.

Flexible Designs

The analog adjust feature allows for the implementation of features such as thermal foldback, interface to sensors, or dimmer range adjust. The LM3450 is compatible with both forward phase (TRIAC) and reverse phase dimmers and can be used in either a single or two stage configuration.

Robust and Reliable

Dynamic hold circuitry allows for robustness to line disturbances to maintain current regulation, accuracy, and dimming performance over different line voltages and applications.

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