High-Brightness LED Lighting Solutions

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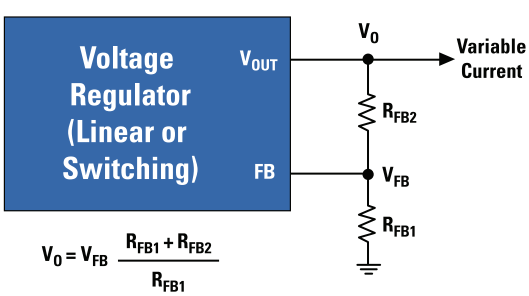
Overview

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 that 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.

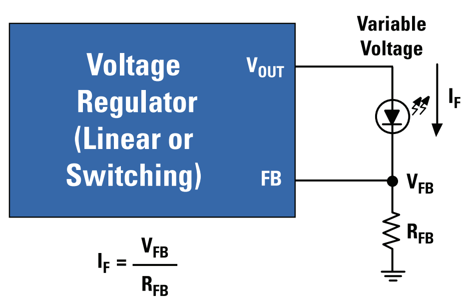
High-Brightness LEDs: Input Voltage and Forward Voltage

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



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 possible: linear regulators and buck regulators.

The simplest method is to use a linear regulator. 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 and low parts count, and generate no 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 second possibility 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 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 as general illumination, situations arise in which the input voltage varies above and below the forward voltage of the LED string.

For these cases, a regulator is needed that can both buck and boost the output as needed. Possible topologies include the buck-boost regulator, the SEPIC regulator, the Cuk regulator, and the flyback regulator. In all of these topologies the power-switch current exceeds the LED current and varies as input voltage varies. 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 to be used.

LED Drivers and Controllers

Switched-Capacitor Boost High-Power LED Drivers

Product ID	Input Range (V)	Output Voltage (V)	Current or Voltage Sourced	Total LED Current (mA)	Switching Frequency (MHz)	Number of LEDs	Dimming Type	Packaging
LM2753	3 to 5.5	5	Voltage	400	0.725	1	Analog	LLP-10
LM2754	2.8 to 5.5	5	Current	800	1	1 to 4	Analog	LLP-24

Inductive Boost High-Brightness LED Drivers

Product ID	Input Range (V)	Max Output Voltage (V)	Typical Switch Current (mA)	Switching Frequency (MHz)	Number of LEDs	Dimming Type	Key Features	Packaging
LM3224	2.7 to 7	20	2450	0.6/1.25	1	PWM	White-LED Flash/Torch application	MSOP-8
LM3551/2	2.7 to 5.5	11	2100	1.25	1 to 4	Analog	Flash LED application	LLP-14
LM2698	2.2 to 12	17.5	1900	0.6/1.25	1 to 4	Analog	1.9A switch, input undervoltage	MSOP-8
LM2700	2.2 to 12	17.5	3600	0.6/1.25	1 to 4	Analog	3.6A switch, input undervoltage	TSSOP-14, LLP-14
LM2735x/y	2.7 to 5.5	24	2450	0.55/1.6	1 to 5	Analog	2.45A switch, internally compensated	SOT23-5, LLP-6, eMSOP-8
LM5000	3.1 to 40	75	2000	0.3/0.7/0.6/1.2	1 to 20	Analog	2A switch, no compensation required	TSSOP-16, LLP-16
LM5001	3.1 to 75	75	1000	Up to 1.5	1 to 20	Analog	1A switch, no compensation required	SO-8, LLP-8
LM5002	3.1 to 75	75	500	Up to 1.5	1 to 20	Analog	500 mA switch, internally compensated	SO-8, LLP-8
LM2733	2.7 to 14	40	1000	0.6/1.6	1 to 8	Analog	1A switch, internally compensated	SOT23-5
LM27313	2.7 to 14	30	800	1.6	1 to 6	Analog	800 mA switch, internally compensated	SOT23-5
New **LM3410***	2.7 to 5.5	24	2100	0.525/1.6	1 to 5	PWM	Ultra-low stand by current of 80 nA, internally compensated	SOT23-5, LLP-6, eMSOP-8

*** Preferred device: This part, featuring high efficiency and ease-of-use, is specifically designed for driving high-brightness LEDs.**

Inductive Buck High-Brightness LED Drivers

Product ID	Input Range (V)	Output Voltage (V)	Total LED Current (mA)	Switching Frequency (MHz)	Number of LEDs	Dimming Type	Key Features	Packaging
LM3402/HV*	6 to 42/6 to 75	37/67	525	Adjustable up to 1 MHz	1 to 9/15	PWM	200 mV feedback voltage, fast PWM dimming	MSOP-8
LM3404/HV*	6 to 42/6 to 75	37/67	1000	Adjustable up to 1 MHz	1 to 9/15	PWM	200 mV feedback voltage, fast PWM dimming	SOIC-8
New **LM3405A***	3 to 22	20	1000	1.6 MHz	1 to 3	PWM	200 mV feedback voltage, fast PWM dimming, thin package	SOT23-6
LM5010/A	8/6 to 75	67	1000	Adjustable up to 1 MHz	1 to 15	PWM	NonSynch, internal high-side N FET	eTSSOP-14, LLP-10
LM5007	9 to 75	67	700	Adjustable up to 800 kHz	1 to 15	PWM	NonSynch, internal high-side N FET	MSOP-8
New **LM3407***	4.5 to 30	27	350	Adjustable up to 1 MHz	1 to 7	PWM	Constant frequency PWM with true average current detection	eMSOP-8

High-Brightness LED Controllers

Product ID	Topology	Input Range (V)	Output Voltage (V)	Max LED Current (mA)	Switching Frequency (MHz)	Number of LEDs	Dimming Type	Key Features	Packaging
New **LM3401***	Buck/ Hysteretic Controller	4.5 to 35	Up to 35	3A	Adjustable to 2 MHz	1 to 9	PWM	Dual-side hysteresis, very low reference voltage and short propagation delay	MSOP-8
New **LM3433***	Buck	9 to 14	Up to 6	14+	Adjustable up to 1 MHz	—	PWM	Negative output voltage capability allows LED anode to be tied directly to chassis for max. heat sink efficacy	LLP-24
LM5020	Buck/Boost/ Flyback	13 to 100	Adjustable	1A+	Adjustable up to 1 MHz	1 to 20	PWM	Flexible LED drive current with external FET, 500 mV feedback voltage	MSOP-10, LLP-10
LM3478	Buck/Boost/ Flyback	2.97 to 40	Adjustable	1A+	Adjustable up to 1 MHz	1 to 9	PWM	Flexible LED drive current with external FET, 200 mV feedback voltage	MSOP-8
LM5022	Buck/Boost/ Flyback	6 to 60	Adjustable	1A	Adjustable up to 2 MHz	1 to 9	PWM	Flexible LED drive current with external FET, 500 mV feedback voltage	MSOP-10
New **LM3431***	Boost	5 to 36	Up to 40	150 mA/String	Adjustable up to 1 MHZ	3 channels x 10	Analog, PWM	LED protection: short, open and thermal	eTSSOP-28

*** Preferred device: This part, featuring high efficiency and ease-of-use, is specifically designed for driving high-brightness LEDs.**

Switched-Capacitor Solutions

For LED-drive applications, the gain of a switched capacitor converter must be large enough to supply enough boost at minimum V_{IN}, maximum LED voltage, and maximum LED current. This must hold over temperature and process variation. More advanced switched-capacitor techniques can improve overall efficiency, but good inductive solutions will almost always have an efficiency advantage over switched-capacitor solutions.

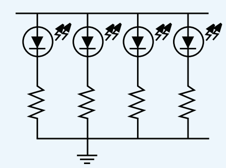
- Switched-capacitor boost LED driver
  - – Lower LED voltage = no change in power consumed
  - – Lower LED voltage = increase in efficiency value

Parallel Topologies

LEDs in parallel: When LEDs are connected off one wire, next to each other in a row; positive (+) to separate grounds (GND).

Advantage: Not restricted to one power rail; good for keypad applications.

LEDs in Parallel

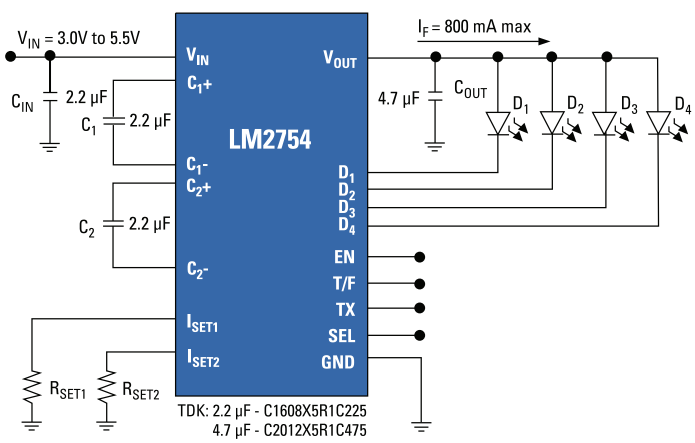


LM2754 800 mA Switched Capacitor Flash LED Driver

Theory of Operation

The LM2754 is an integrated low noise, high current switched capacitor DC-DC converter with four regulated current sinks. The device is optimized for driving 1 to 4 high power white LEDs in parallel with a maximum current of 800 mA. Maximum efficiency is achieved over the input voltage range by actively selecting the proper gain based on the LED forward voltage and current requirements. Two external low power resistors set the desired current for Torch and Flash modes.

LM2754 Typical Application



TDK: 2.2 µF - C1608X5R1C225
4.7 µF - C2012X5R1C475

Inductive-Boost LED Drivers

Inductive-Boost Solutions

Inductive LED drivers are the best solution for currents greater than a few hundred milliamps. The major advantage to inductive-boost drivers is their ability to drive significantly higher current, which is especially good for applications that need many LEDs or are using an LED flash. Another advantage is that these drivers can continuously adjust their gain (PWM or PFM) to change LED brightness.

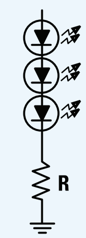
- Inductive-boost LED driver
  – Lower LED voltage = less power consumed
  – Lower LED voltage = no change in efficiency value

Series Topologies

LEDs in series: When all LEDs are connected off one wire in a column, one after another; positive (+) to negative (-).

Advantages: Single output pin, guaranteed current matching.

LEDs in Series

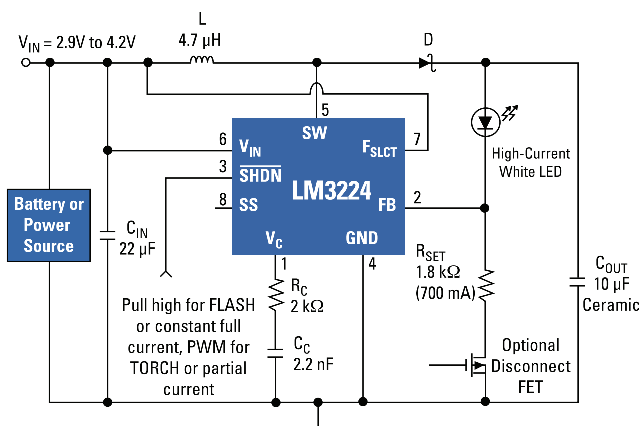


LM3224 Inductive Step-Up Converter with PWM Control for White-LED Flash/Torch Applications

Theory of Operation

The LM3224 is a step-up DC-DC converter with a 0.15W (typ), 2.45A (typ) internal switch and pin-selectable operating frequency. The LM3224 has the ability to convert 3.3V to multiple outputs of 8V, -8V, and 23V. With a high-current switch, it is also ideal for driving high-current white LEDs for flash applications. The LM3224 can be operated at switching frequencies of 615 kHz and 1.25 MHz, allowing for easy filtering. An external compensation pin gives the user flexibility in setting frequency compensation, which makes the use of small, low-ESR ceramic capacitors at the output possible. An external softstart pin allows the user to limit the voltage overshoot at the load terminals during startup.

LM3224 Typical Application Circuit

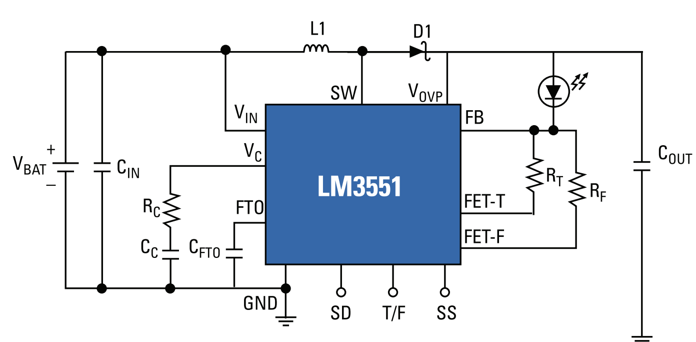


LM3551 High-Current Inductive DC-DC Converter for Flash-LED Applications

Theory of Operation

The LM3551 is a fixed-frequency 1.25 MHz step-up DC-DC converter with up to 700 mA flash-driving capability. The LM3551 can drive a high-power flash LED either in a high-power flash mode and a lower-power torch mode using the TORCH/FLASH pin. An external SD pin is available to put the device into low power shutdown mode.

LM3551 Typical Application Circuit

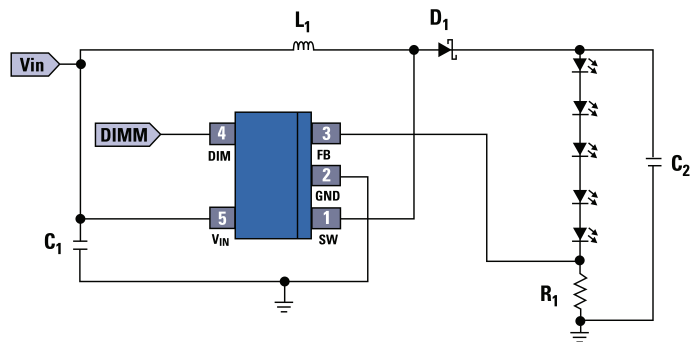


LM3410 Constant current Boost and SEPIC LED Driver with internal compensation

Theory of Operation

The LM3410 LED driver is a monolithic, high frequency, PWM step-up DC/DC converter in 5-pin SOT23, 6-pin LLP, & 8-pin eMSOP packages. With a minimum of external components the LM3410 is easy to use. It can drive 2.5A typical peak currents with an internal 160m NMOS switch. Switching frequency is internally set to either 525 kHz or 1.60 MHz. Even though the operating frequency is high, efficiencies up to 85% are easy to achieve. External shutdown is included, featuring an ultra-low stand-by current of 80 nA. The LM3410 utilizes current-mode control and internal compensation to provide high-performance over a wide range of operating conditions. Additional features include dimming, pulse-by-pulse current limit, and thermal shutdown.

LM3410 Typical Application

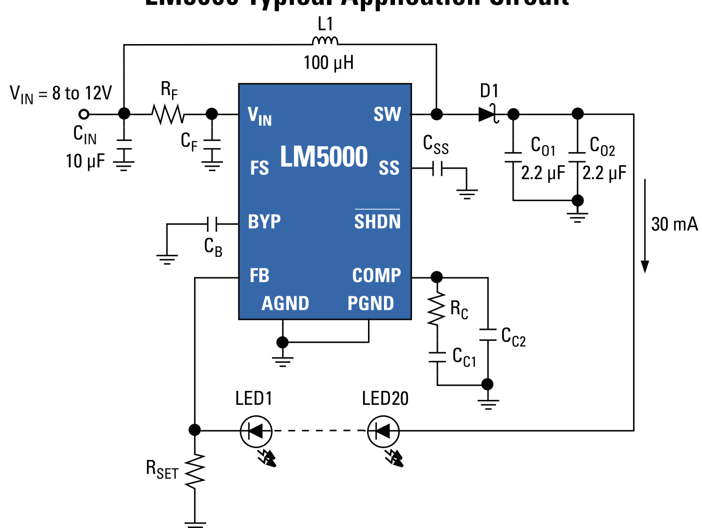


LM5000 High-Voltage Boost Regulator

Theory of Operation

This circuit boosts the input voltage in order to keep 20 LEDs in a single-series string, ensuring that the same current flows through each device. The high voltage capability of the LM5000 makes it simple to power long strings with no external power switches required.

LM5000 Typical Application Circuit

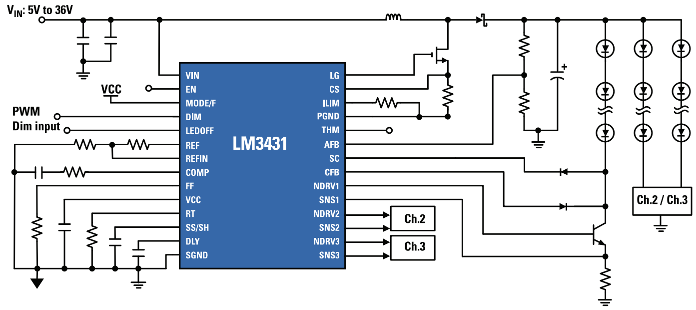


LM3431 3-Channel Constant Current LED Driver with Integrated Boost Controller

Theory of Operation

The LM3431 is a 3-channel linear current controller combined with a boost switching controller ideal for driving LED backlight panels in space critical applications. The LM3431 drives 3 external NPN transistors or MOSFETs to deliver high accuracy constant current to 3 LED strings. Output current is adjustable to drive strings in excess of 200 mA. The boost controller drives an external NFET switch for stepup regulation from input voltages between 5V-36V. The LM3431 features LED cathode feedback to minimize regulator headroom and optimize efficiency. A DIM input pin controls LED brightness from analog or digital control signals. Dimming frequencies up to 25 kHz are possible with a contrast ratio of 100:1. Contrast ratios greater than 1000:1 are possible at lower dimming frequencies. The LM3431 eliminates audible noise problems by maintaining constant output voltage regulation during LED dimming. Additional features include LED short and open protection, fault delay/error flag, cycle by cycle current limit, and thermal shutdown for both the IC and LED array.

LM3431 Typical Application Circuit

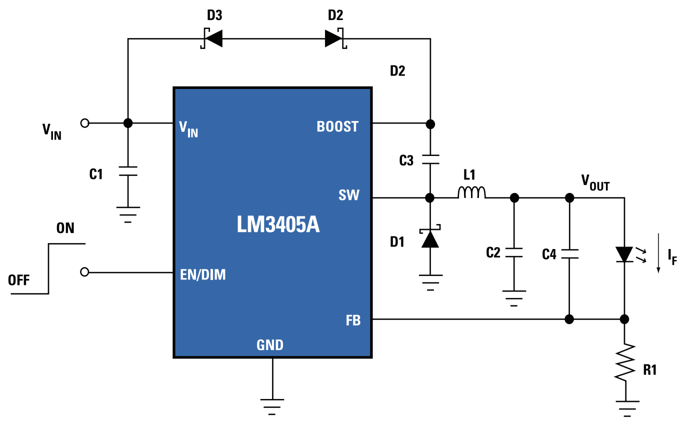


LM3405A 1A constant Buck LED Driver with internal compensation

Theory of Operation

The LM3405A is a 1A constant current buck LED driver designed to provide a simple, high efficiency solution for driving high power LEDs. With a 0.205V reference voltage feedback control to minimize power dissipation, an external resistor sets the current as needed for driving various types of LEDs. Switching frequency is internally set to 1.6MHz. The LM3405A utilizes current-mode control and internal compensation offering ease of use and predictable, high performance regulation over a wide range of operating conditions. With a maximum input voltage of 22V, it can drive up to 5 High Brightness LEDs in series at 1A forward current, with the single LED forward voltage of approximately 3.7V. Additional features include user accessible EN/DIM pin for enabling and PWM dimming of LEDs, thermal shutdown, cycle-by-cycle current limit and over-current protection.

LM3405A Typical Appliction

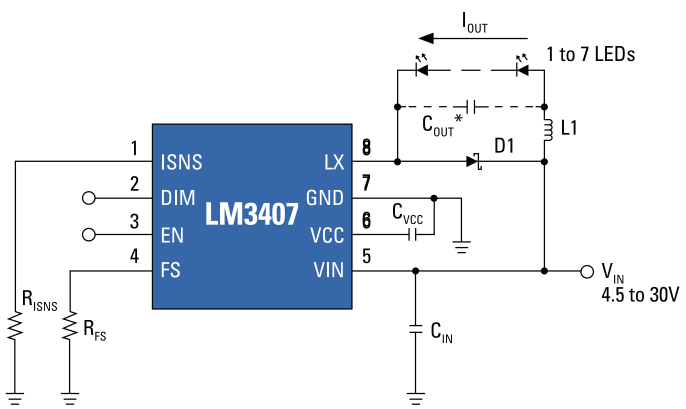


LM3407 350 mA, Constant Current Output Floating Buck Switching Converter for High Power LEDs

Theory of Operation

The LM3407 is a constant current output floating buck switching converter designed to provide constant current to high power LEDs. The device is ideal for automotive, industrial and general lighting applications. The LM3407 has an integrated power N-MOSFET. An external 1% resistor allows the converter output voltage to adjust as needed to deliver constant current accurately to a serially connected LED string. The switching frequency is adjustable from 300 kHz to 1 MHz. The LM3407 features a dimming input to enable LED brightness control by Pulse Width Modulation (PWM).

LM3407 Typical Appliction

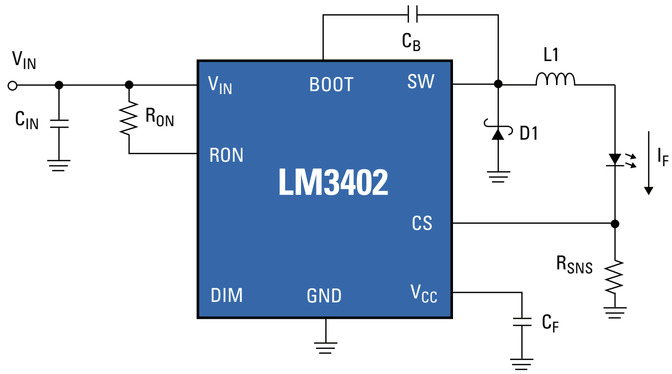


LM3402 0.5A LED Driver with 200 mV Feedback Voltage and V_{IN} up to 75V

Theory of Operation

The LM3402/02HV is a compact, efficient constant current step-down (Buck) monolithic switching regulator designed to drive high power LEDs. Ideal for automotive, industrial, and general lighting applications, it contains a high-side N-MOSFET switch capable of driving up to 500 mA and a low 200 mV feedback voltage. The wide input voltage range of 6V to 42V for the LM3402 and 6V to 75V for the LM3402HV, makes this an ideal LED driver for a wide range of applications.

LM3402 Typical Application

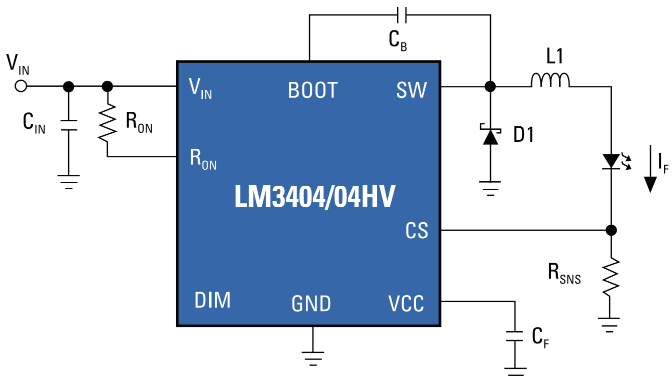


LM3404 1.0A Constant Current Buck Regulator for Driving High Power LEDs

Theory of Operation

The LM3404/04HV are monolithic switching regulators designed to deliver constant currents to high power LEDs. Ideal for automotive, industrial, and general lighting applications, they contain a high-side N-MOSFET switch with a current limit of 1.2A (typical) for step-down (Buck) regulators. Hysteretic control with controlled on-time, coupled with an external resistor allow the converter output voltage to adjust as needed. Output current dimming via PWM, broken/open LED protection, low-power shutdown and thermal shutdown complete the feature set.

LM3404/04HV Typical Application Circuit



Inductive-Buck LED Controllers

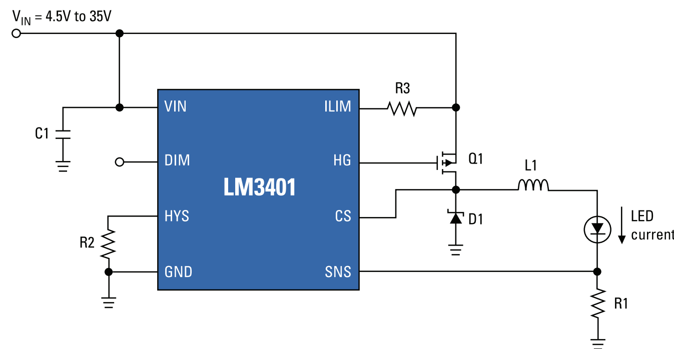
LM3401 Hysteresis PFET controller for High Power LED Drive

Theory of Operation

The LM3401 drives an external P-MOSFET switch for Buck regulators. The LM3401 delivers constant current within ±6% accuracy to a wide variety and number of series connected LEDs. Output current is adjusted with an external current sensing resistor to drive high power LEDs in excess of 1A.

For improved accuracy and efficiency, the LM3401 features dual-side hysteresis, very low reference voltage, and short propagation delay. A cycle by cycle current limit provides protection against over current and short circuit failures. Additional features include adjustable hysteresis and a CMOS compatible input pin for PWM dimming.

LM3401 Typical Appliction

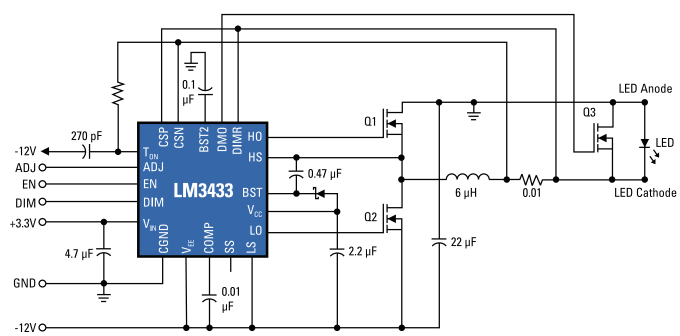


LM3433 Common Anode Capable High Brightness LED Driver with High Frequency Dimming from the PowerWise® Family

Theory of Operation

The LM3433 is an adaptive constant on-time DC/DC buck constant current controller (a true current source). The LM3433 provides a constant current for illuminating high power LEDs. The output configuration allows the anodes of multiple LEDs to be tied directly to the ground referenced chassis for maximum heat sink efficacy. The high frequency capable architecture allows the use of small external passive components and no output capacitor while maintaining low LED ripple current. The PWM functions by shorting out the LED with a parallel switch allowing high PWM dimming frequencies. Additional features include thermal shutdown, VCC under-voltage lockout, and logic level shutdown mode.

LM3433 Typical Appliction

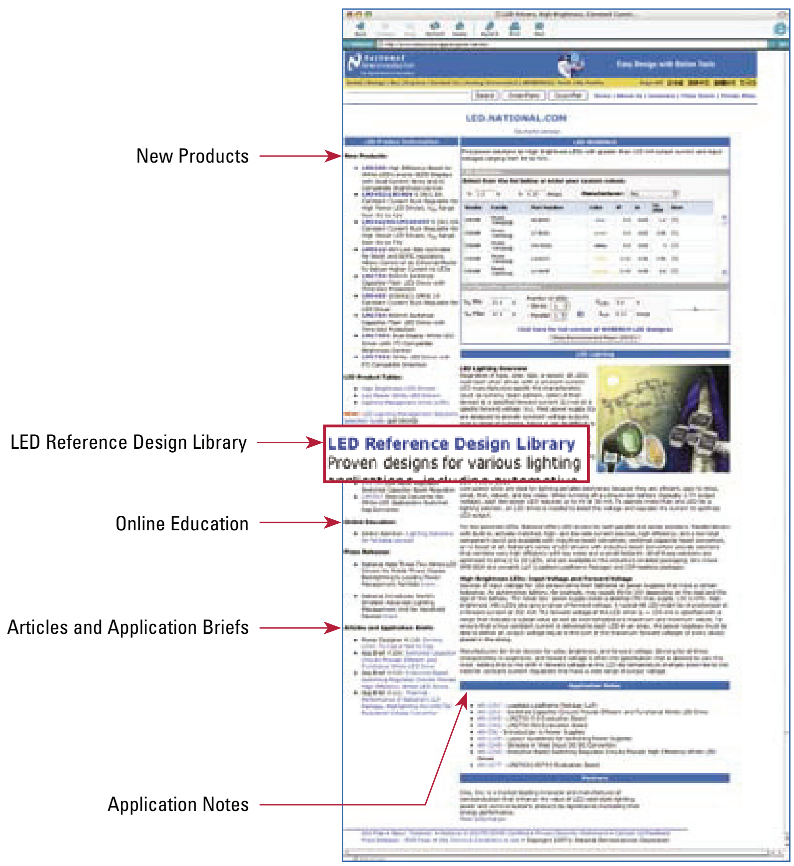


High-Brightness LED Reference Design

Solution	Part Used	Description	Page
Portable Application	LM2623	Boost Converter Driving High Brightness 1W LED from Single or Two Cell Battery Pack	14
MR 16 Application	LM3405A	12V AC input for MR 16 LED bulbs	15
Automotive Applications	LM5007	Buck Converter for Automotive Applications, Driving 1 to 2 High-Brightness 1W LEDs	16
	LM5010	Buck Converter for Automotive Tail Light Application, 1 High-Brightness LED, 300 or 900 mA	17
24V BUS Applications	LM3402	6 InGaN White LEDs, 330 mA	18
	LM5020	3W High-Brightness LED, 900 mA with Dimming Control Output	19
48V BUS Application	LM3402HV	12 InGaP LEDs, 360 mA	20
Wide Input Applications	LM3402	1 InGaN LED, 350 mA	21
		3 InGaP LED, 350 mA	22
	LM3402HV	1 InGaN LEDs, 350 mA	23

LED Reference Design Library

For proven designs of various lighting applications, including automotive, general illumination, flashlights, and architectural lighting, please visit the **LED Reference Design Library** section at **national.com/LED** or visit **www.national.com**



LM2623
Boost Converter Driving High-Brightness 1W LED from Single or Two Cell Battery Pack

Description:

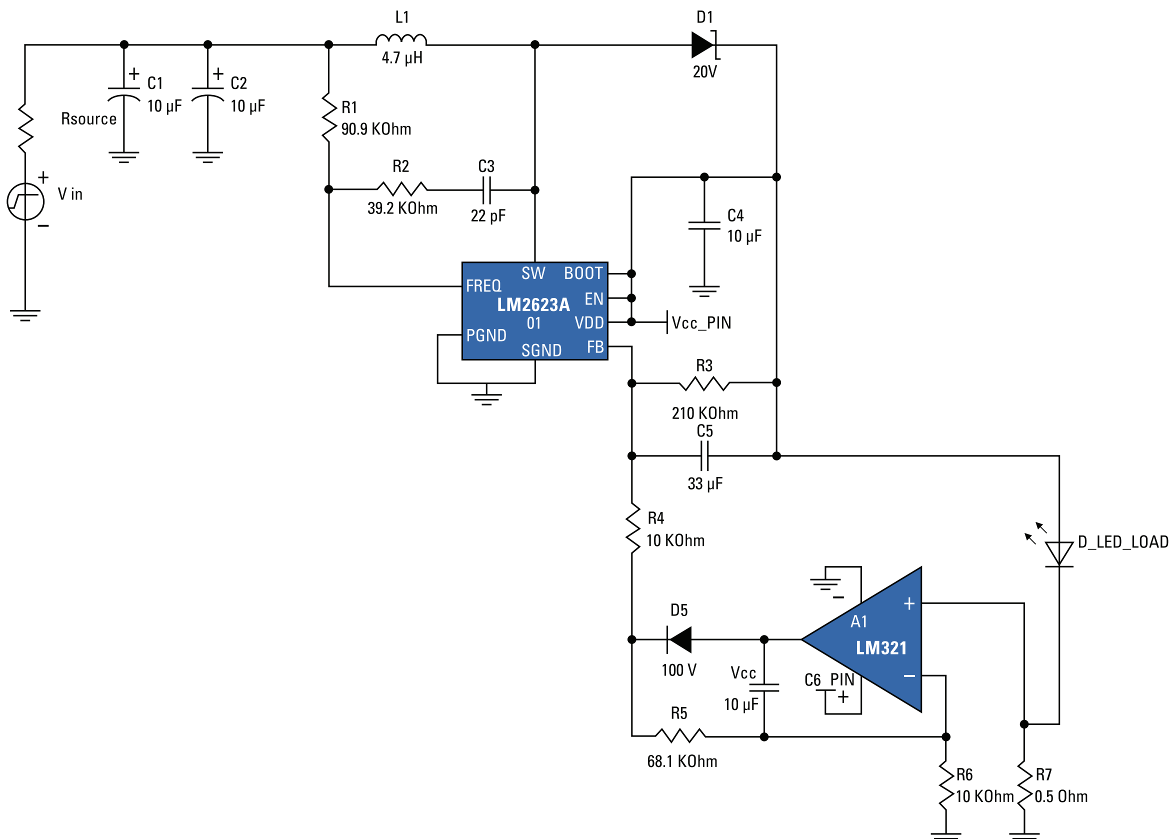
- This design is a basic boost that is capable of providing constant current of 350 mA and an open circuit maximum voltage of 5V at high efficiency.
- It is designed to power 1W LED from single or two cells.

Specification:

Inputs	Output #1
Vin Min = 1.5V	Vout1 = 3.5V (typ.)
Vin Max = 3.3V	Iout1 = 0.350A

Theory of Operation

- It uses the LM2623MM, a mini SO-8 package boost switcher with an internal 1.2A switch, to boost the input voltage from 1.5 – 3.3V to the required LED voltage of 3.5V (typ.).
- With an LED present, as the output voltage ramps to approximately 3.5V, the LED will turn on causing current to flow through R7.
- The voltage across R7 is amplified by a factor of 7X by the SOT-5 LM321MF and the gain resistors R5 and R6. This produces a voltage of 1.24 volts at the junction of R4 and R5 when 350 mA flows through the LED. The 1.24 volts regulates the LED current at a constant value by the internal LM2623 feedback control.
- The LM2623A should be used for single cell operation since it guarantees a peak switch current greater than 2A.



For more informations of reference designs, please visit
www.national.com/webench/ledrefdesigns.do

MR16 Application

LM3405A

Description:

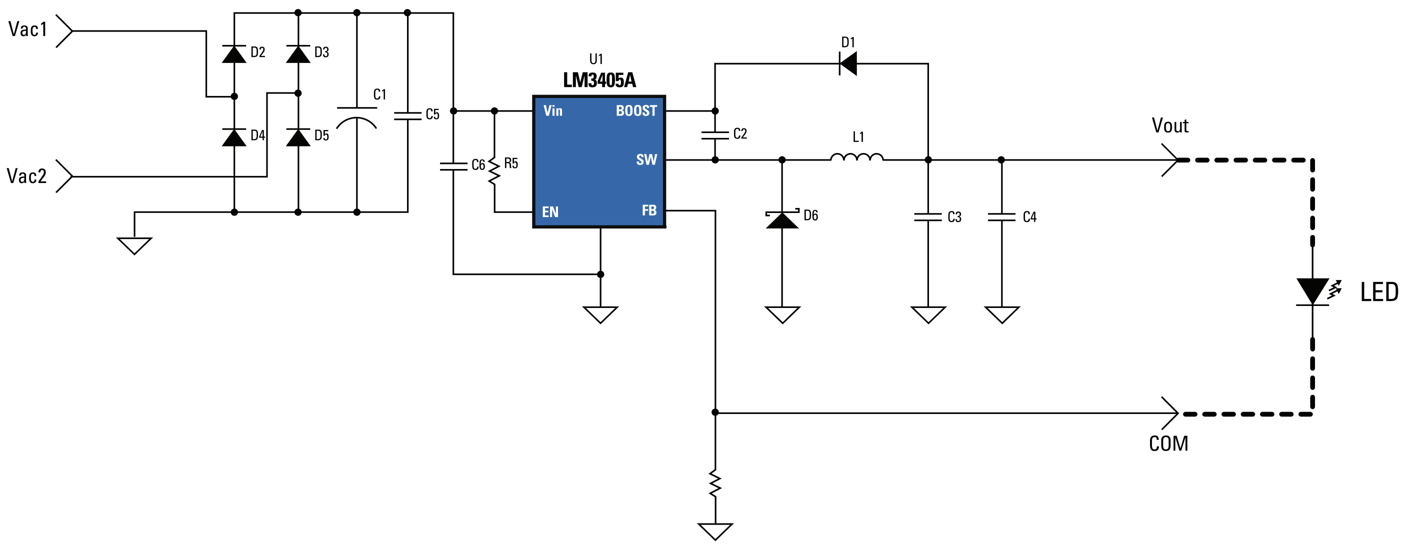
This design is an example of an MR16 form factor LED bulb to replace a halogen light bulb. It is capable of providing 600mA constant current to drive high brightness LEDs from a 12V AC source.

Specification:

Inputs	Output #1
Vin Min = 10.8 VAC	Vout1 = 3.8V
Vin Max = 13.2 VAC	Iout1 = 0.6A

Theory of Operation

- It uses LM3405A LED driver, a current mode control buck switching regulator in tiny SOT23 package to drive high power LEDs (Typical Vf = 3.8V).
- With a 0.205V reference voltage feedback control to minimize power dissipation, an external resistor sets the current as needed for driving various types of LEDs.
- As the input voltage of MR16 is 12 VAC, a bridge rectifer is required to rectify the AC input to DC level in order to provide supply to LM3405A LED driver. With wide input operating voltage range of the LM3405A (from 3 VDC to 22 VDC), a very small input capacitor can maintain continuous operation.
- Switching frequency is internally set to 1.6 MHz, allowing the use of extremely small surface mount inductors and chip capacitors.
- All these factors help to squeeze the overall dimensions of the PCB to fit the stringent space constraints of the MR16 form factor and this makes LM3405A the best LED driver for this application.



Automotive Applications

LM5007
Buck Converter for Automotive Applications, Driving 1 to 2 High-Brightness 1W LEDs

Description:

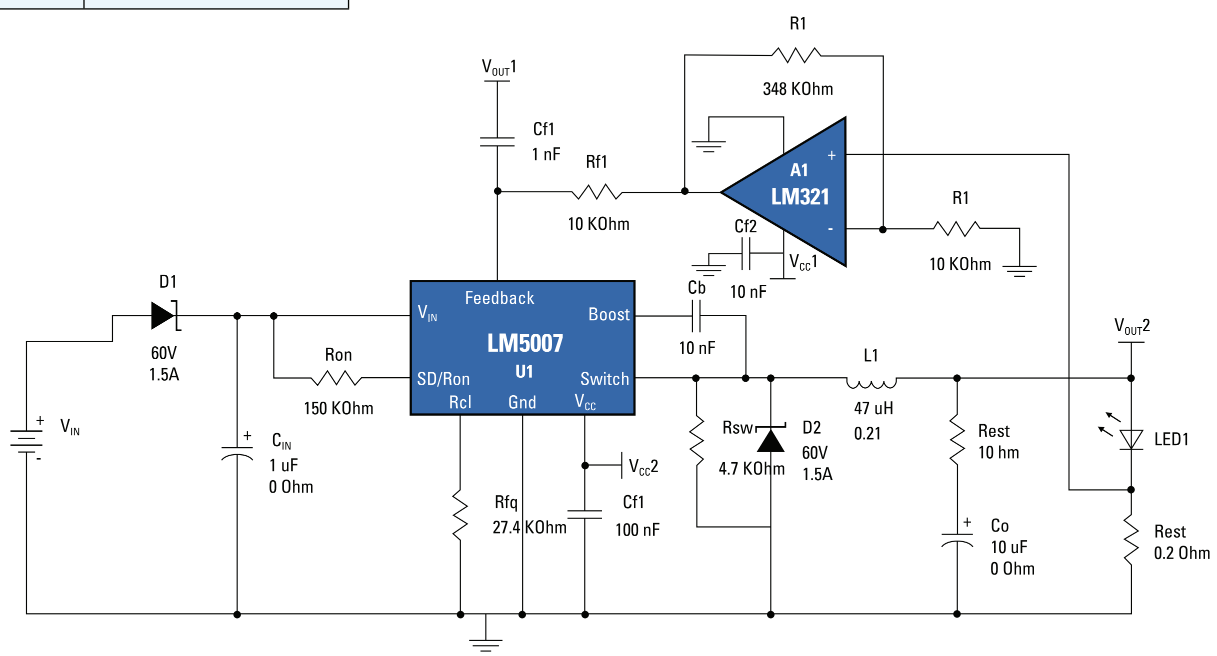
- This circuit is designed to replace a single-filament incandescent bulb in an automobile tail light, brake light, turn signal, reverse light, or interior light (dome light, map light).
- The basic design is a buck current regulator that is capable of providing 350 mA constant current for powering one to two 1W LED from the input voltage of 9V to 40V.
- It is suitable for standard passenger cars and trucks with 8V – 16V batteries as well as freight trucks, tow trucks, fork lifts, and other vehicles that use a double lead-acid battery system (16V – 32V)

Specification:

Inputs	Output #1
Vin Min = 9.0V	Vout1 = 2.3V (typ.)
Vin Max = 40.0V	Iout1 = 0.35A

Theory of Operation

- It uses the LM5007MM, a MSOP-8 package buck switcher with an internal 0.7A N-FET switch, to step down the input voltage from 9 – 40V to the required LED voltage of 2.3V (typ.).
- With an LED present, as the output voltage ramps to approximately 2.3V, the LED will turn on causing current to flow through R_{set}.
- The voltage across R_{set} is amplified by a factor of 35X by the SOT-5 LM321MF and the gain resistors Rf and Ri. This produces a voltage of 2.45 volts at the junction of Rf and Rff when 350 mA flows through the LED. The 2.45 volts regulates the LED current at a constant value by the LM5007 internal feedback comparator.
- The LM5007 can withstand inputs voltages of up to 75V. This circuit does not need additional protection from 'load dump' events of up to 75V.
- The brightness of the LED can be dimmed with a PWM input by placing a signal-level NFET from the RON pin to ground and driving the gate with the PWM signal.



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LM5010
Buck Converter for Automotive Tail Light Application, 1 High-Brightness LED, 300 or 900 mA

Description:

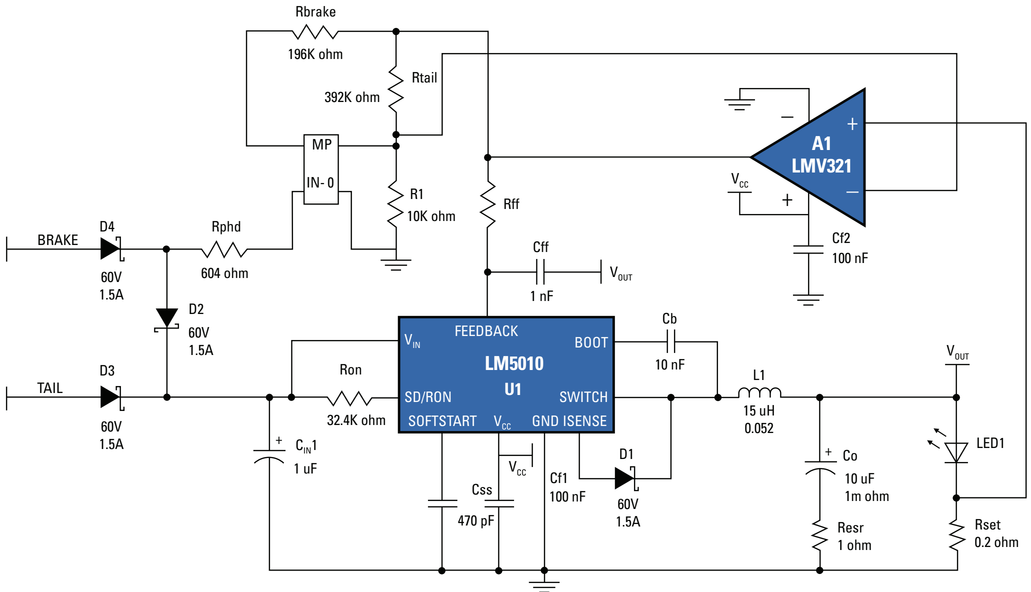
- This circuit is designed to replace a dual-filament incandescent bulb in a combined brake/tail light for automotive use.
- The basic design is a buck current regulator that is capable of providing up to 900 mA constant current.
- When power is applied to the 'Tail' input the current in the LED is regulated to 300 mA. When power is applied to the 'Brake' input or both inputs simultaneously, the current in the LED increases to 900 mA.
- The 'Brake' and 'Tail' input voltage can vary between 8V and 40V. This makes the circuit suitable for standard passenger cars and trucks with 8V – 16V batteries as well as freight trucks, tow trucks, fork lifts, and other vehicles that use a double lead-acid battery system, or 16V – 32V.

Specification:

Inputs	Output #1
Vin Min = 8.0V	Vout1 = 2.5V (typ.)
Vin Max = 40.0V	Iout1 = 0.9A

Theory of Operation

- It uses the LM5010MH, a TSSOP-14EP package buck switcher with an internal 1A N-FET switch, to step down the input voltage from 8 – 40V to the required LED voltage of 2.5V (typ.).
- When power is applied to the 'Tail' input, the voltage across the Rset is amplified by a factor of 39x by the SOT LM321MF and the gain resistor Rtail and Ri. And the amplification gain is equal to Rtail/Ri. The current LED is regulated to 300 mA.
- When power is applied to the 'Brake' input or both input simultaneously, the photoMOS is turned on. The amplification gain from the voltage across the Rset is reduced to 13x, which is determined by (Rbrake // Rtail) / Ri. Thus, the current in the LED increases to 900 mA.
- Diodes D3 and D4 provide reverse battery protection, and D2 ensures that a 'Brake' input supercedes a 'Tail' input.
- The LM5010 can withstand inputs voltages of up to 75V. This circuit does not need additional protection from 'load dump' events up to 75V.
- The brightness of the LED can be dimmed with a PWM input by placing a signal-level NFET from the RON pin to ground and driving the gate with the PWM signal. This circuit is also compatible with 100 Hz PWM of the input voltage for 'theater dimming' of interior lights.



LM3402
6 InGaN White LEDs, 330 mA

Description:

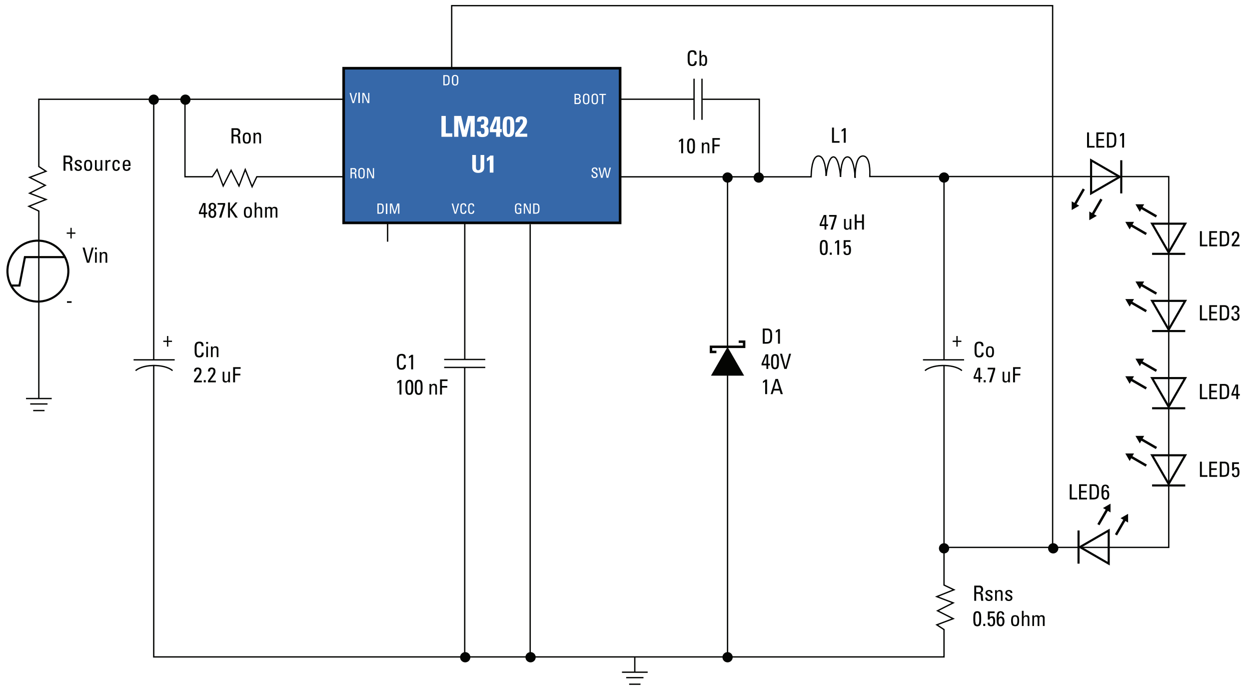
- This design is a basic buck current regulator that is capable of providing constant current of 330 mA.
- This circuit is designed to drive an array of six series-connected InGaN white 1W LEDs (typical V_F 20.4V total) from an input of 24V ±10%.

Specification:

Inputs	Output #1
Vin Min = 21.6V	Vout1 = 20.4V (typ.)
Vin Max = 26.4V	Iout1 = 0.33A

Theory of Operation

- It uses LM3402, a compact & efficient constant current step down switching regulator with an internal 500 mA N-FET switch, to step down the input voltage from 21.6 – 26.4V to the required six series-connected InGaN white LEDs of typical V_F 20.4V total.
- The low 200 mV feedback voltage greatly reduces the power dissipation of current sense resistor.
- The switching frequency of this application is approximately 350 kHz to provide the smallest component footprint and LED ripple current possible.
- Ripple current in the LED array is 2 mA peak-to-peak, or less than 1% of the average LED current.



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LM5020
3W High-Brightness LED, 900 mA with Dimming Control Output

Description:

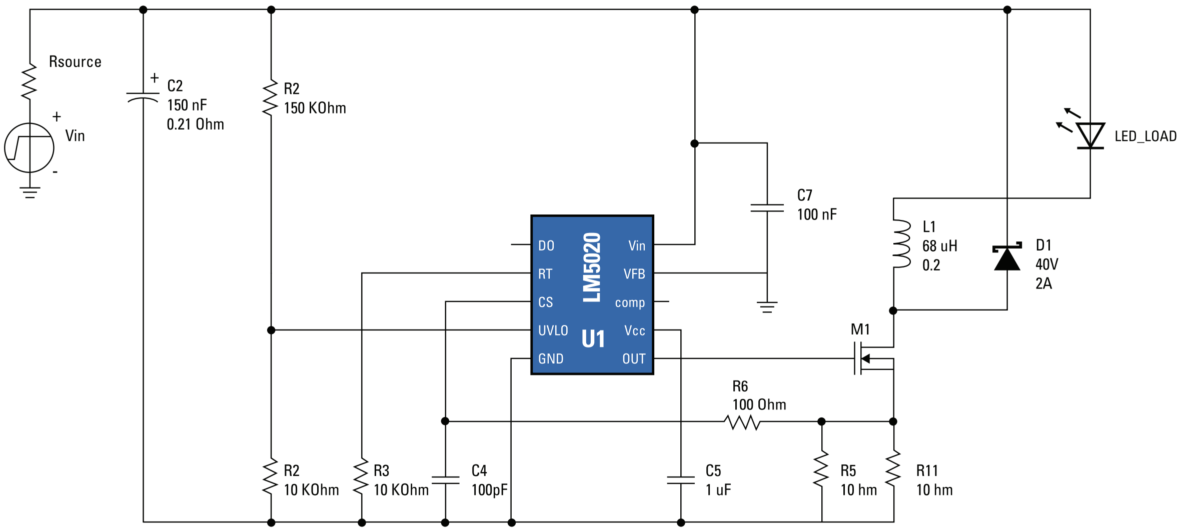
- The LM5020 design is a low – side switch buck current regulator for driving very bright high current LEDs using a peak current control scheme.
- The circuit is designed to drive a 900 mA high power & brightness LED from the input range of 20 – 28V.

Specification:

Inputs	Output #1
Vin Min = 20V	Vout1 = 3V (typ.)
Vin Max = 28V	Iout1 = 0.9A

Theory of Operation

- It uses LM5020, a 100V Peak Current Mode PWM Controller, to step down the input voltage from 20 – 28V to a 900 mA high power & brightness of typical V_F 3V forward voltage.
- The oscillator frequency is set by resistor R3, which is approximately 600 kHz in this application example.
- Since the voltage control loop is not used as operating at constant current mode, the voltage feedback pin is grounded and the comp pin is left open.
- The peak current of the LED is controlled by internal current sense comparator from CS pin.
- With M1 ON, L1 inductor current increases. The inductor current is conducted directly through the LED, so the LED current is likewise increasing. The LED current is sensed by the parallel combination of R5 and R11, and this signal is filtered to remove high frequency switching noise by the low pass filter consisting of R6 and C4. Current increases until the current sense input, CS, reaches its threshold of 0.5V. At this time, M1 is started to turn off. With M1 OFF, the inductor voltage reverses, the freewheel diode, D1, turns ON. The current decreases linearly in the loop consisting of LED, L1, and D1 until the next oscillator cycle begin.
- Since there is no directly controlled output voltage, which one would usually find in a voltage converter, no output capacitor is used. Therefore, there is no capacitive discharge delay when the converter is turned off by the PWM signal.



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48V BUS Application

LM3402HV
12 InGaP LEDs, 360 mA

Description:

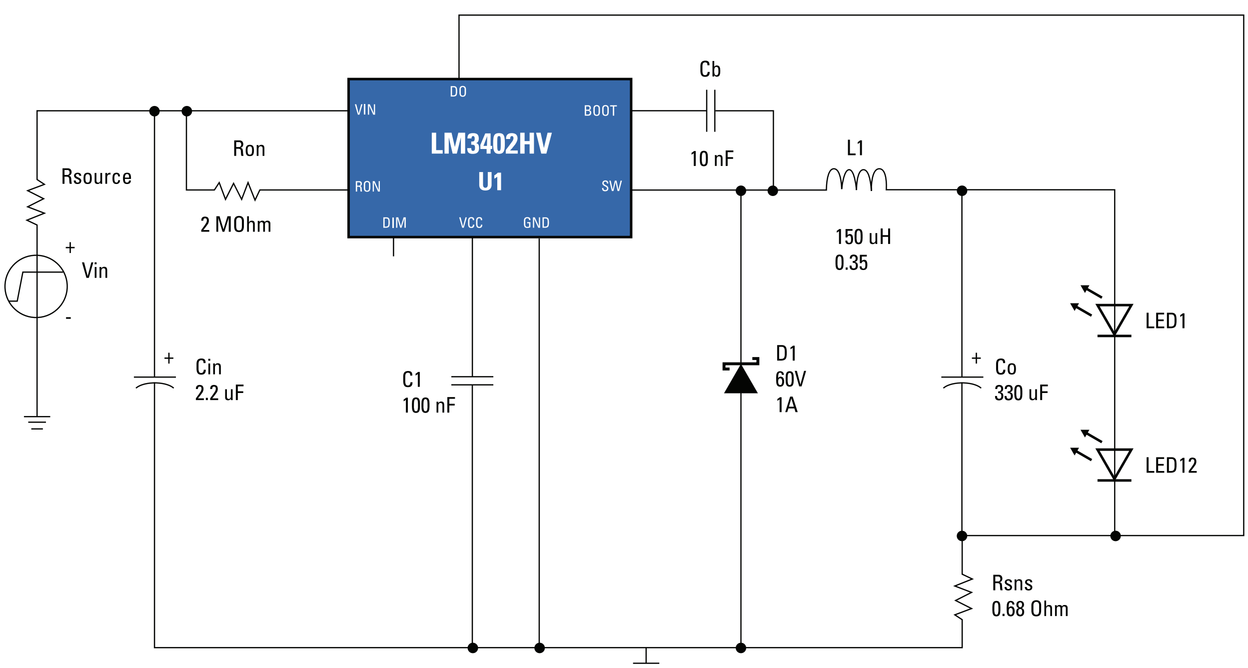
- This design is a basic buck current regulator that is capable of providing constant current of 360 mA.
- This demonstration circuit is designed to drive a string of 12 InGaP 1W LEDs (V_F total about 40.2V) from the input voltage of 47 - 49V.

Specification:

Inputs	Output #1
Vin Min = 47V	Vout1 = 40.2V (typ.)
Vin Max = 49V	Iout1 = 0.360A

Theory of Operation

- It uses LM3402HV, a compact & efficient constant current step down switching regulator with an internal 500 mA N-FET switch, to step down the input voltage from 47 – 49V to the required twelve series-connected InGaP LEDs of typical V_F 40.2V total.
- The low 200 mV feedback voltage greatly reduces the power dissipation of current sense resistor.
- The switching frequency of this application is approximately 200 kHz, in order to optimize the power efficiency and solution size.
- Ripple current in the LED array is 40 mA peak-to-peak, or less than 12% of the average LED current.



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Wide Input Applications

LM3402
1 InGaN LED, 350 mA

Description:

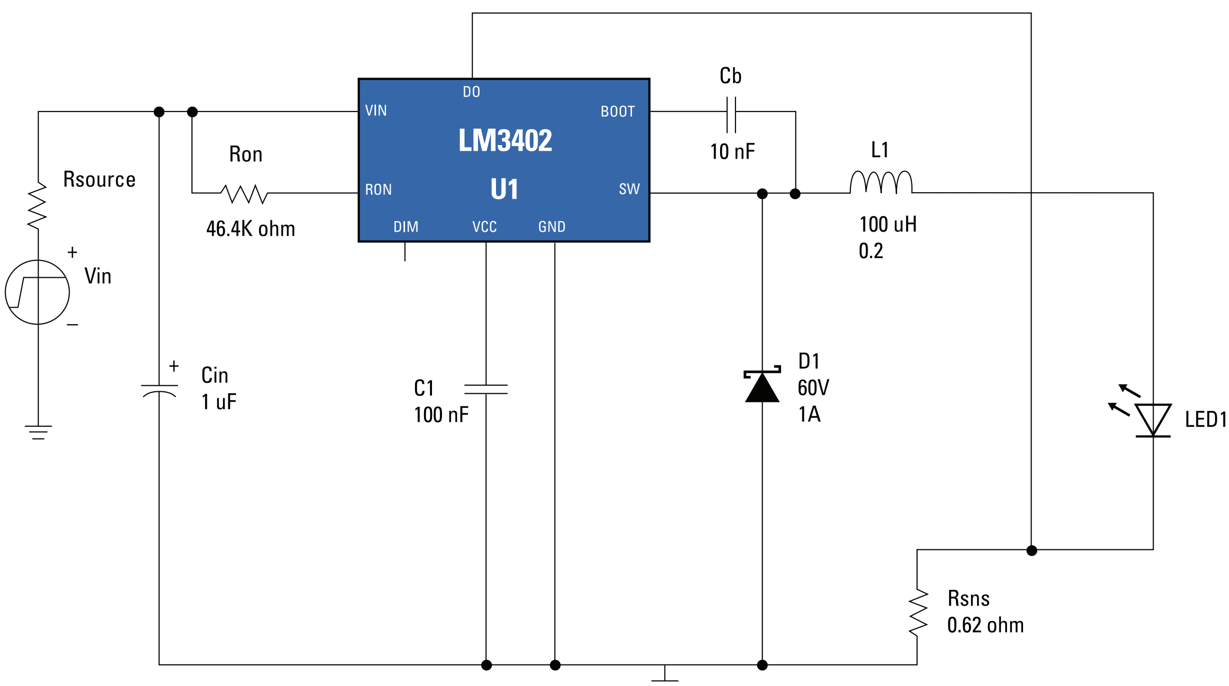
- This design is a basic buck current regulator that is capable of providing constant current of 350 mA.
- This circuit has been designed to drive a InGaN white, blue or green 1W LED (typ.V_F of 3.5V) from the very wide input range of 6V – 42V.

Specification:

Inputs	Output #1
Vin Min = 6V	Vout1 = 3.5V (typ.)
Vin Max = 42V	Iout1 = 0.350A

Theory of Operation

- It uses LM3402, a compact & efficient constant current step down switching regulator with an internal 500 mA N-FET switch, to step down the very wide input voltage from 6 – 42V to a InGaN white, blue and green LED of typical 3.5V.
- The low 200 mV feedback voltage greatly reduces the power dissipation of current sense resistor.
- The switching frequency of this application is 500 kHz ±10% within the whole input range, to optimize solution size & power efficiency.
- When powered from a 24V ±5% input, the circuit will maintain the average LED current to within 10% of 350 mA. The ripple current will not exceed 70 mA peak-to-peak.



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Wide Input Applications

LM3402
3 InGaP LEDs, 350 mA

Description:

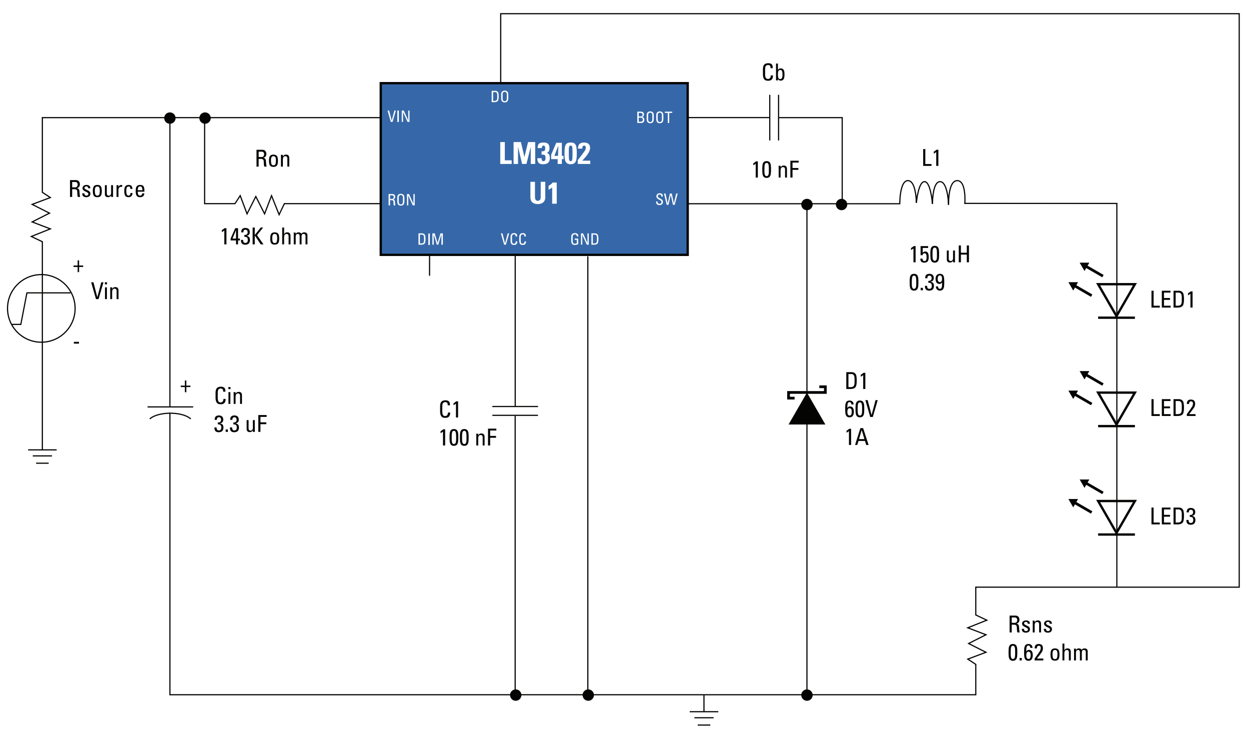
- This design is a basic buck current regulator that is capable of providing constant current of 350 mA.
- This circuit has been designed to drive a string of three series connected 1W InGaP LEDs (total V_O = 10.7V) operated from the wide input range of 14V – 42V.

Specification:

Inputs	Output #1
Vin Min = 14V	Vout1 = 10.7V (typ.)
Vin Max = 42V	Iout1 = 0.350A

Theory of Operation

- It uses LM3402, a compact & efficient constant current step down switching regulator with an internal 500 mA N-FET switch, to step down the wide input voltage from 14 – 42V to the required three series-connected InGaP LEDs of typical V_F 10.7V total.
- The low 200 mV feedback voltage greatly reduces the power dissipation of current sense resistor.
- The switching frequency of this application is approximately 700 kHz at 24 V_{IN}, to minimize the total board size. The ripple current of LED array is 140 mA or less.
- In expectation of fast PWM dimming requirements there is no output capacitor used in this design.



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LM3402HV
1 InGaN LED, 350 mA

Description:

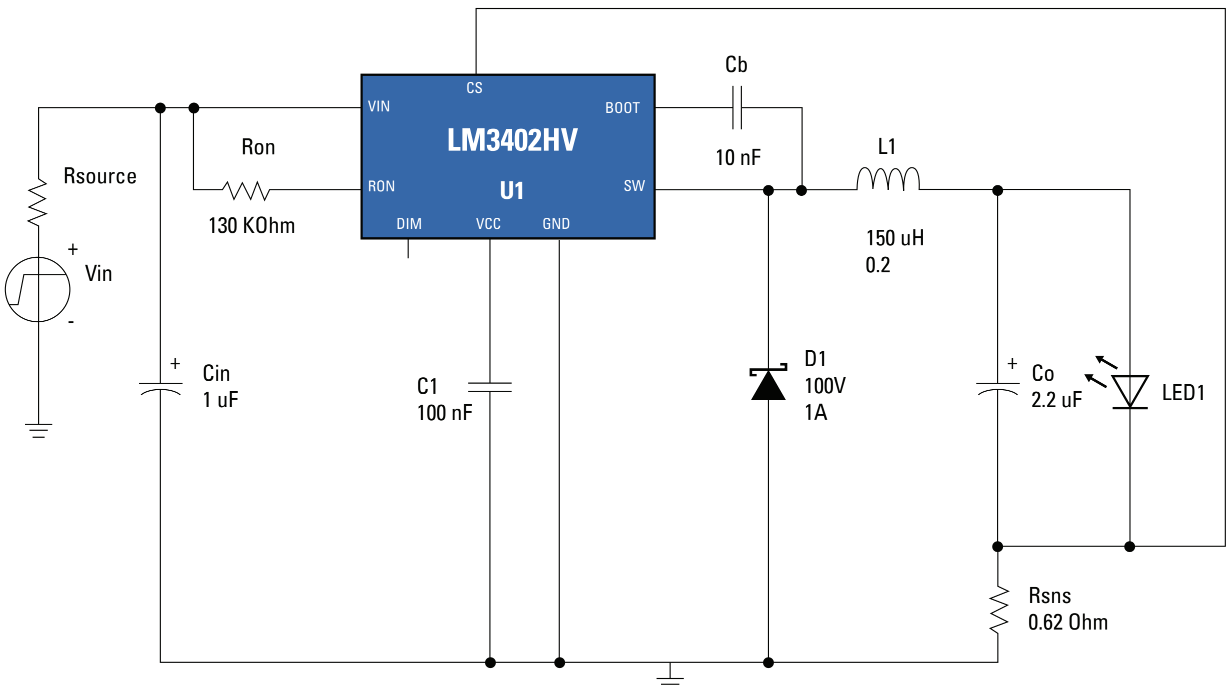
- This design is a basic buck current regulator that is capable of providing constant current of 350 mA.
- This circuit has been designed to drive a 1W InGaN white, blue, or green LED (typ. V_F of 3.5V) operated from the ultra wide input range of 6V – 75V.

Specification:

Inputs	Output #1
Vin Min = 6V	Vout1 = 3.5V (typ.)
Vin Max = 75V	Iout1 = 0.350A

Theory of Operation

- It uses LM3402HV, a compact & efficient constant current step down switching regulator with an internal 500 mA N-FET switch, to step down the wide input voltage from 6 – 75V to a InGaN white, blue, or green LED of typical 3.5V.
- The low 200 mV feedback voltage greatly reduces the power dissipation of current sense resistor.
- The switching frequency of this application is 250 kHz ±10% within the whole input range, in order to optimize the solution size & power efficiency.
- When powered from a 48V ±5% input the circuit will maintain the average LED current to within 10% of 350 mA. The ripple current will not exceed 70 mA peak-to-peak.



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Driving LEDs: To Cap or Not to Cap

— By Chris Richardson, Applications Engineer

Introduction

High-brightness LEDs are available today with forward currents more than 100 times greater than their predecessors. These new devices are not just high brightness, but are high power as well. Single die with dissipations of 5W and multi-die modules with power in excess of 25W are now available. The requirements of high efficiency and low dissipation dictate a switching power supply for this new generation of High-Brightness (HB), High-Power (HP) LEDs, as a voltage regulator and a current limiting resistor are no longer appropriate. High-brightness, high-power LEDs require a constant-current source to take full advantage of their ever-increasing luminous efficiency and vibrant, pure color. The topology of choice for this new breed of switching constant current sources is the basic buck converter. The most convincing argument for using a buck converter is the ease with which this simple DC-DC converter can be turned into a constant-current source. This article will explain the selection of, or possible exclusion of, an output capacitor when designing a buck regulator for constant-current drive of HB LEDs.

Controlled Current

The buck regulator is uniquely suited to be a constant current driver because the output inductor is in series with the load. Regardless of whether a buck regulator is used as a voltage source or a current source, selection of the inductor forms the cornerstone of the system design. With an inductor in series with the output, the average inductor current is always equal to the average output current, and the buck converter naturally maintains control of the AC-current ripple. By definition, the LED drive is a constant load system; hence a large amount of output capacitance is not necessary to maintain V_O during load transients.

No Output Cap Yields High Output Impedance

In theory, a perfect current source has infinite output impedance, allowing the voltage to slew infinitely fast in order to maintain a constant current. For switching regulator designers who have concentrated on voltage regulators, this concept may take a moment to sink in. Completely removing the output capacitor from a buck regulator forces the output impedance to depend on the inductor. Without any capacitance to oppose changes in V_O, the output current (referred to as forward current, or I_F) slew rate depends entirely upon the inductance, the input voltage, and the output voltage. (V_O is equal to the combined forward voltage, V_F, of each series-connected LED)

LED manufacturers generally recommend a ripple current, ΔI_F, of ±5% to ±20% of the DC forward current. Over the typical switching regulator frequency range of 50 kHz to 2 MHz the ripple itself is not visible to the human eye. These limits come from increasing thermal

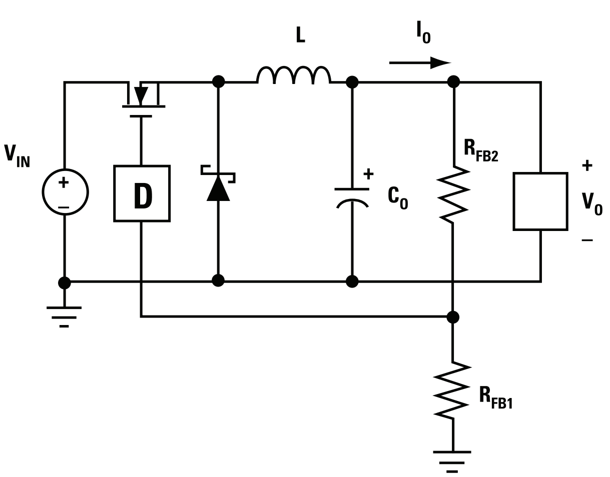

Figure 1a. Traditional Buck Voltage Regulator

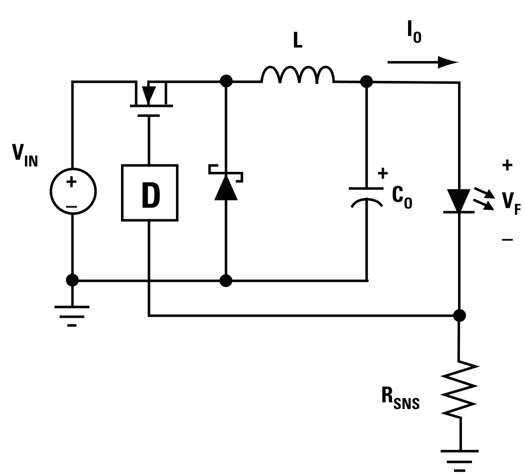

Figure 1b. Buck Current Regulator

losses at higher ripple current (a property of the LED semiconductor PN junction itself) and a practical limit to the inductance used. The percentages are similar to the recommended current ripple ratio in buck voltage regulators. Inductor selection for a fixed-frequency current regulator is therefore governed by the same equations as a voltage regulator:

$$L = \frac{V_{IN}}{V_F} \times \frac{V_{IN} - V_F}{\Delta i_L \times f_{SW}}$$

One difference is that the inductance used for current regulators without output capacitors tends to be higher because the drive currents for the emerging standards of 1W, 3W, and 5W HB LEDs are 350 mA, 700 mA, and 1A respectively. Modern buck voltage regulators tend to use inductors in the range of 0.1 µH to 10 µH with saturation currents from 5A to 50A. Current drivers at similar switching frequencies tend to require inductors ranging from 10 µH to 1000 µH and saturation currents ranging from 0.5A to 5A.

The main goal of high output impedance is to create a system capable of responding to PWM dimming signals, the preferred method of controlling the light output of LEDs. The dimming signal might be applied to the enable pin of the regulator, in which case the output current can slew from zero to the target and back to zero without the delay of C_0 being charged and discharged. For even faster, higher resolution dimming, a shunt switch, usually a MOSFET, can be placed in parallel with the LED array, allowing the continuous flow of current at all times. Again, with no output capacitor to slow the slew rate, dimming frequencies into the 10's of kHz are possible. This is a critical requirement in applications such as backlighting of flat-panel displays, and the creation of white light using an RGB array.

Using an Output Capacitor Reduces Size and Cost

Some amount of output capacitance can be useful as an AC current filter. Applications such as retrofitting of incandescent and halogen lights often require that the LED and driver be placed in a small space formerly occupied by a light bulb. Invariably the inductor is the largest, most expensive component after the LEDs themselves. For the sake of efficiency (especially important in cramped quarters), the designer generally chooses the lowest switching frequency that allows the solution (mostly the inductor) to fit. Allowing a large ripple current in the inductor and filtering the LED current results in a smaller, less expensive solution. For example, to drive a single white LED ($V_F \approx 3.5V$) at 1A with a ripple current Δi_F of ±5% from an input of 12V at 500 kHz would require a 50 µH inductor with a current rating of 1.1A. A typical ferrite core device that fits this application might be 10 mm square and 4.5 mm in height. In contrast, if the inductor ripple current is allowed to increase to ±30% (typical for a low-current voltage regulator) then the inductance required is less than 10 µH, and an inductor measuring 6.0 mm square and only 2.8 mm in height size can be used. The output capacitance required is calculated based on the dynamic resistance, r_D, of the LED, the sense resistance, R_{SNS}, and the impedance of the capacitor at the switching frequency, using the

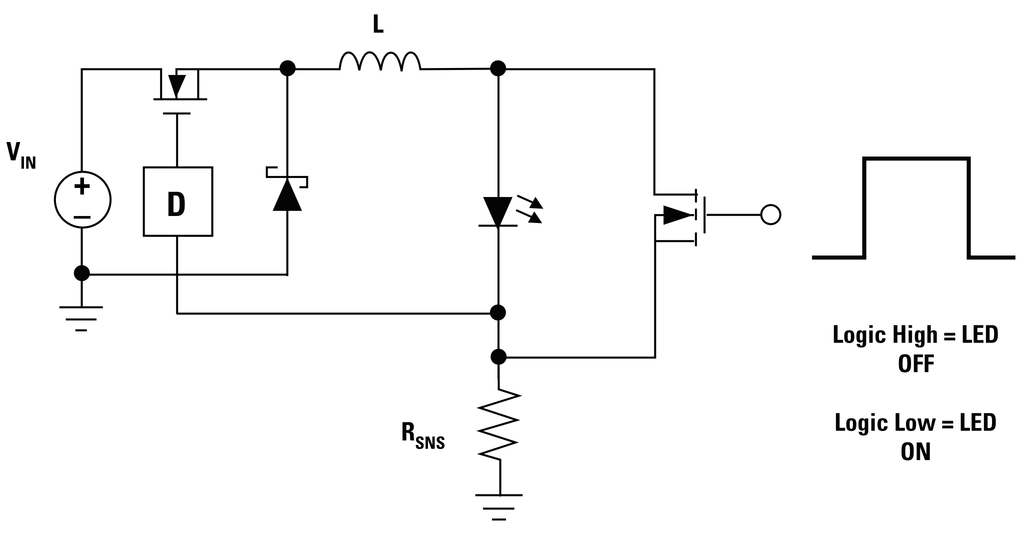

Figure 2. Dimming with a Parallel NFET

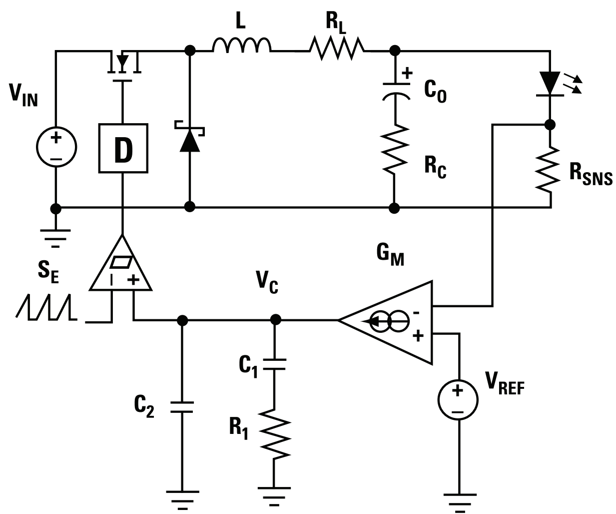

Figure 3a: PWM Regulator

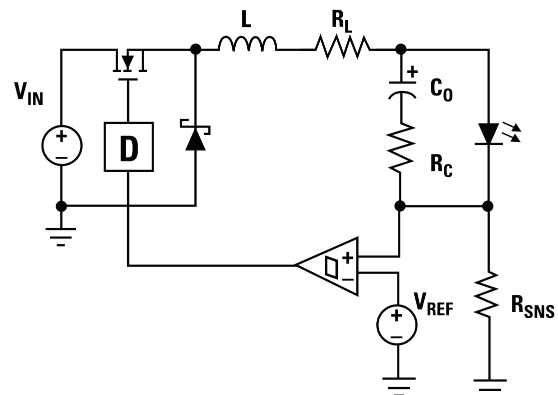

Figure 3b: Comparator-based Regulator

following expressions:

$$C_O = \frac{1}{2\pi \times f_{SW} \times (ESR + Z_C)}, \quad Z_C = \frac{\Delta i_F}{\Delta i_L - \Delta i_F} \times r_D$$

Typical values for output capacitors range from 0.1 µF to 10 µF, a perfect fit for ceramic capacitors. In many applications, the addition of an output capacitor reduces both the size and the cost of the total solution.

Output Capacitor Placement

For buck regulators that use PWM-based control, such as Voltage Mode (VM) and Current Mode (CM) the output capacitor should be connected from the regulator output to system ground, identical to a normal buck regulator. (***Figure 3a***) This way, the control-to-output transfer function of the system can be analyzed with the same equations used when designing a voltage regulator. When using comparator-based control, such as hysteretic or Constant on-Time (COT), the output capacitor should be placed in parallel with the LED array. (***Figure 3b***) In hysteretic voltage regulator circuits, this technique is often used to increase the percentage of in-phase voltage ripple at the feedback node. For the current regulator, it forces both the ripple current through C_0 and the forward current through the LEDs to sum at the input to the switching comparator. The voltage waveform across R_{SNS} is therefore in-phase with the switching node waveform, and the result is predictable operation with high noise rejection. The combination of low output capacitance and high inductor current ripple actually makes hysteretic and COT current regulators more reliable and easier to design than voltage regulators.

Conclusion

The high brightness, high power LED represents the biggest change in lighting design since the introduction of fluorescent bulbs. Using LEDs requires a fundamental change in the complexity of electronics used for lighting systems. Currently a large portion of LED lighting design is retrofitting of incandescent, halogen, and fluorescent installations. Such systems rarely include sophisticated dimming control, and place a high value on small size. These are the applications where an output capacitor is a welcome addition to the driver circuit.

In the future, the higher cost of LEDs for general lighting will be balanced by new levels of control over brightness, tone, and color. Lighting in homes and businesses will require fast PWM dimming, requiring current drivers to minimize or eliminate their output capacitance. These systems will draw upon experience from today's fast-dimming applications which have already shed the output capacitor to provide the best response time.

Design Tools and Packaging

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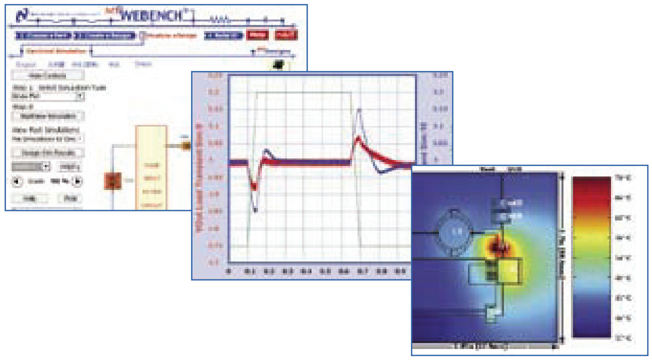

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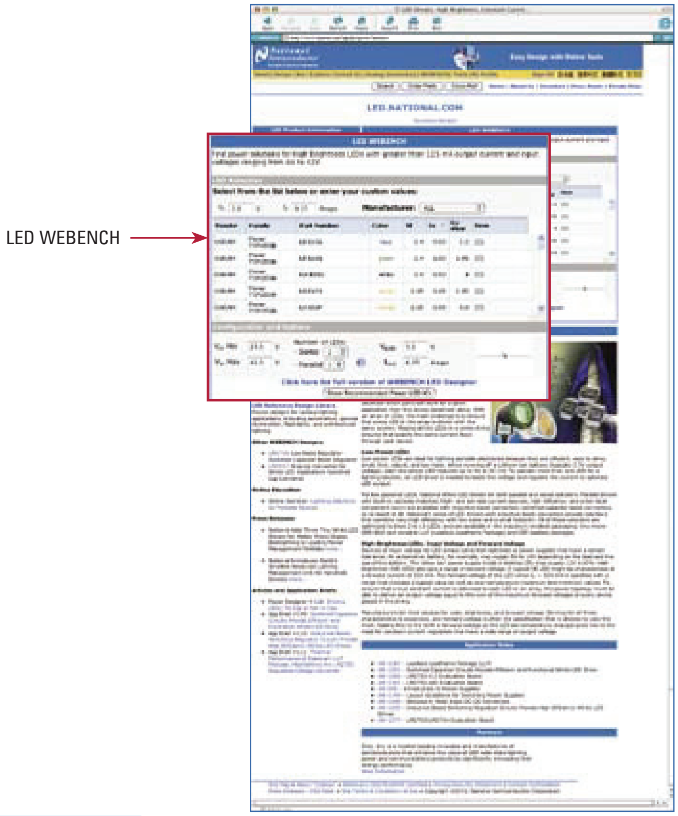

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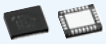
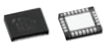
Packaging Solutions



Leadless Leadframe Package (LLP®)

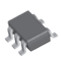
National's LLP® package provides excellent power dissipation capability in a very small footprint.

θ_{JA} shown are typical



LLP® (Leadless leadframe package)
θ_{JA} 40-60 °C/W

SOIC
θ_{JA} 100 to 190°C/W



SOT-23
θ_{JA} 240 °C/W

micro SMD
θ_{JA} 220 °C/W

TSSOP
θ_{JA} 150 °C/W

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