LED Lighting Management Solutions

Fall 2005

National Semiconductor
The Sight & Sound of Information

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 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.

Low-Power LEDs

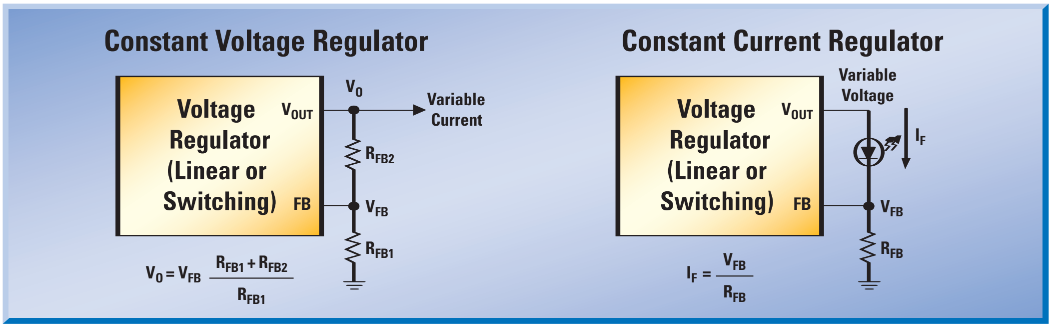
Low-power LEDs are ideal for lighting portable electronics because they are efficient, easy to drive, small, thin, robust, and low noise. When running off a Lithium-Ion battery (typically 3.7V output voltage), each low-power LED requires up to 4V at 30 mA. To operate more than one LED for a lighting solution, an LED driver is needed to boost the voltage and regulate the current to optimize LED output.

For low-powered LEDs, National offers LED drivers for both parallel and series solutions. Parallel drivers with built-in, actively-matched, high- and low-side current sources, high efficiency, and a low total component count are available with inductive-boost converters, switched-capacitor boost converters, or no boost at all. National's series of LED drivers with inductive-boost converters provide solutions that combine very high efficiency with low noise and a small footprint. All of these solutions are optimized to drive 2 to 10 LEDs, and are available in the industry's smallest packaging: tiny micro-SMD BGA and versatile LLP® (Leadless Leadframe Package) and CSP-leadless packages.

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.



Inductive-Boost White-LED Drivers (LEDs in Series)

Product ID	Voltage Range (V)	Output Voltage (V)	Total LED Current (mA)	Number of LEDs	Switching Frequency (MHz)	Efficiency Across LED (%)	Switching Type	PWM Dimming	Packaging
LM2703	2.2 to 7	20	60	4	—	80	PFM	Yes	SOT23-5
LM2704	2.2 to 7	20	120	4	—	80	PFM	Yes	SOT23-5
LM2705	2.2 to 7	20	40	2	—	80	PFM	Yes	SOT23-5
LM2707	2.2 to 7	20	120	4	1	80	PWM	Yes	SOT23-5
LM3224	2.7 to 7	20	1000	20	1.25	90	PWM	Yes	MSOIC-8
LM3500/1	2.7 to 7	16	70	4	1	85	PWM	Yes	micro SMD-8
LM3520	2.7 to 5.5	—	120	4, OLED sub-display	1.1	—	PWM	Yes	LLP-14
LM3551	2.7 to 7.5	5	700	1 Flash LED	1	80	PWM	No	LLP-14
LM3557	2.7 to 7.5	—	150	5	1.25	85	Fixed freq.	No	LLP-8

Switched-Capacitor Boost White-LED Drivers (LEDs in Parallel)

Product ID	Voltage Range (V)	Output Voltage (V)	Total LED Current (mA)	Number of LEDs	Switching Frequency (MHz)	Efficiency Across LED (%)	Current or Voltage Sourced	PWM Dimming	Packaging
LM2750	2.7 to 5.6	5.2	120	6	1.7	62	Voltage sourced	Yes	LLP-10
LM2751	2.7 to 5.6	5.2	120	6	1.7	—	Voltage sourced	Yes	LLP-10
LM2794/95	2.7 to 5.5	—	80	4	0.515	80	Current sourced	Yes	micro SMD-14
LM2796	2.7 to 5.5	—	140	7 (4 x 3)	0.5	80	Current sourced	Yes	micro SMD-18
LM27951	2.8 to 5.5	—	80	4	0.5	80	Current sourced	Yes	LLP-14
LM27953	2.7 to 6.5	—	80	4	0.5	—	Current sourced	Yes	micro SMD-18
LM27961	2.7 to 5.5	—	140	7 (4 x 3)	0.5	—	Current sourced	Yes	micro SMD-18
LM27964	2.7 to 5.5	—	200	Up to 16	0.5	—	Current sourced	Yes	LLP-24
LM3354	2.5 to 5.5	5	90	—	1	90	Voltage sourced	Yes	MSOIC-10

High-Voltage/High-Power LED Drivers

Product ID	Voltage Range (V)	Output Voltage (V)	Total LED Current (mA)	Switching Frequency (kHz)	Topology	PWM Dimming	Key Features
LM2698	4.5 to 5.5	14.8 to 16	160	600	Boost	Yes	Drives 32 white LEDs in eight strings of 4; 20 mA per string
LM2734	8 to 11	0.8 to 7	350	1600	Buck	No	Drives 1 high-power white LED at 350 mA
LM2737	12 to 14	3 to 4	2000	800	Buck	Yes	Drives 1 high-power LED at 2A
LM3478	12 to 30	13 to 24	350	400	SEPIC	Yes	Drives 6 LEDs of any color at 350 mA from various battery or regulated inputs
LM3485	8 to 32	2.3 to 30	350/1400	Variable	Buck	No	Drives any Luxeon LED or strings of LEDs depending on V_{IN} (min)
LM5000	7 to 11	74 to 80	30	700000	Boost	No	Drives 20 white LEDs in a single string at 30 mA to light a vanity mirror
LM5007	9 to 40	2.3 to 8	350	Variable	Buck	No	Drives 1-2 Luxeon LEDs, designed for exterior automotive use
LM5010	8 to 40	2.3 to 8	300/900	Variable	Buck	No	Drives 1-2 Luxeon LEDs at different currents from separate power inputs, designed for exterior automotive use

Low-Voltage LED Lighting

Inductive-Boost Solutions

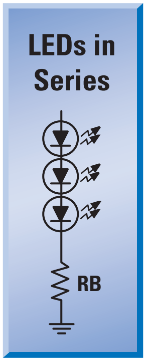
Inductive LED drivers are best used in solutions where size is not an issue, while keeping the highest power efficiency. The major advantage to inductive-boost drivers is their ability to drive significantly higher current, which is especially good for applications that need many LEDs or are using an 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 (-).

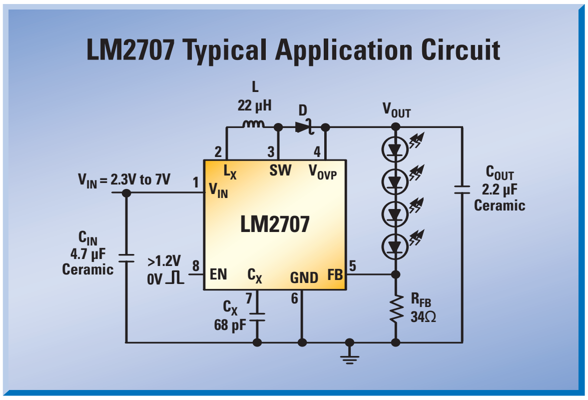
Advantage: Single output pin, guaranteed matching.



LM2707 Inductive-Boost Series LED Driver with Programmable Oscillator Frequency

Theory of Operation

The LM2707 is a magnetic-boost regulator specifically designed for white-LED drive applications. Tightly regulated LED currents, exceptional LED brightness uniformity, and very high LED-drive power efficiency (>80%) can all be achieved by stacking the LEDs in series between the LM2707 output and the low-voltage feedback pin (0.515V).

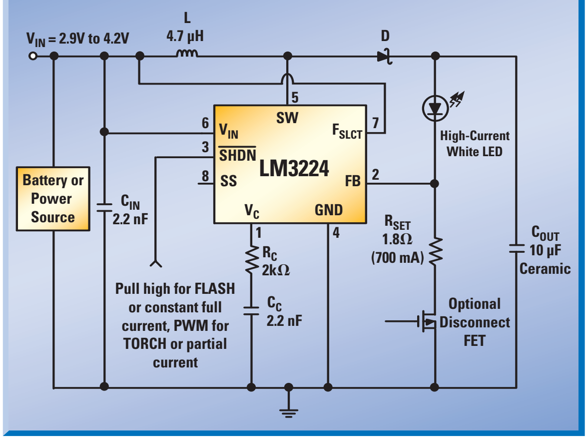


LM3224 Inductive Step-Up Converter with PWM Control for White-LED Flash/Torch Applications

Theory of Operation

The LM3224 is a step-up DC-DC converter with a 0.15Ω (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

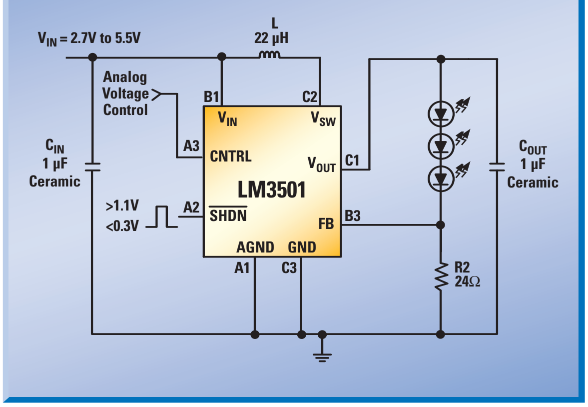


LM3501 Synchronous Step-Up DC-DC Converter for White-LED Applications

Theory of Operation

The LM3501 is a fixed-frequency synchronous step-up DC-DC converter ideal for white-LED applications for backlighting requiring low current and high efficiency. Its fixed 1-MHz operating frequency allows the use of small, low-ESR capacitors as well as a more predictable frequency spectrum, which is important in cellular phone applications. The LM3501 can drive 2 to 4 white LEDs in series from a single Li-Ion battery or 3-cell NiMH battery with no external rectification diode. For white-LED applications, a single external resistor is used to set the maximum LED current. The white-LED current can easily be adjusted using an external voltage signal from a DAC or microcontroller.

LM3501 Typical Application Circuit

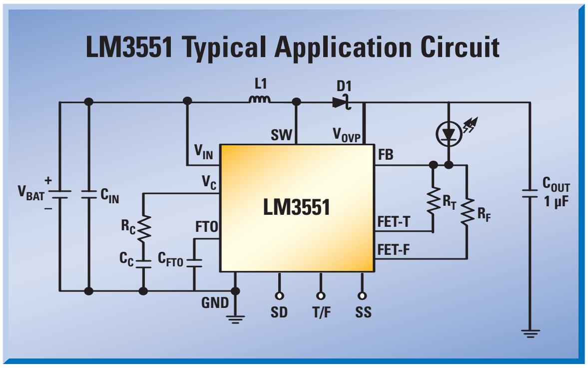


Low-Voltage LED Lighting

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

Theory of Operation

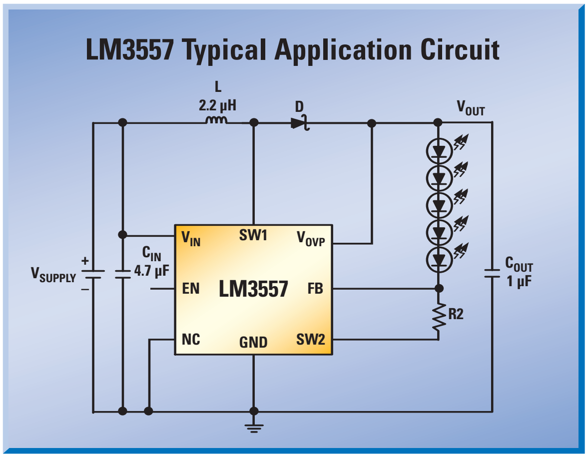
The LM3551 is a fixed-frequency 1.25 MHz step-up DC-DC converter with up to 700 mA flash-driving capability. The LM3551 can drive a high-power flash LED either in a high-power flash mode and a lower-power torch mode using the TORCH/FLASH pin. An external SD pin is available to put the device into low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



LM3557 Inductive Step-Up Converter for White-LED Applications

Theory of Operation

The LM3557 is a complete solution for white-LED drive applications. The LM3557 features a minimal external component count, no DC-current leakage paths to ground, cycle-by-cycle current-limit protection, and output over-voltage protection circuitry. The LM3557 switches at a fixed-frequency of 1.25 MHz, which allows for the use of small external components. The wide input voltage range of the LM3557 allows it to take advantage of multi-cell input applications.



Switched-Capacitor Solutions

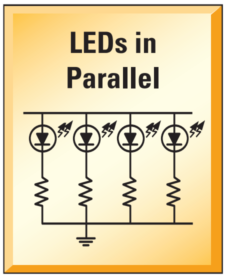
For LED-drive applications, the gain of a switched capacitor converter must be large enough to supply enough boost at minimum V_{IN}, maximum LED voltage, and maximum LED current. This must hold over temperature and process variation. More advanced switched-capacitor techniques can improve overall efficiency.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

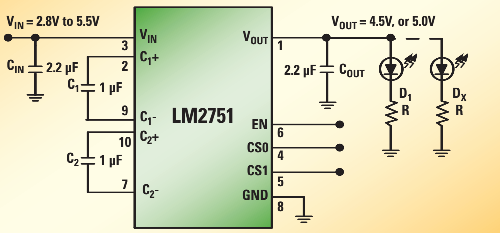


LM2751 Regulated 2X, 1.5X Switched Capacitor White-LED Driver

Theory of Operation

The LM2751 is a constant-frequency switched-capacitor charge pump with regulated output voltage options of 4.5V and 5V. Over the input voltage range of 2.8V to 5.5V, the LM2751 provides up to 150 mA of output current and requires only four low-cost ceramic capacitors for excellent efficiency. It does not require the use of an inductor by operating the charge pump in a gain of 3/2 or 2. The proper gain for maintaining regulation is chosen so that efficiency is maximized over the input voltage range. The LM2751 uses constant-frequency pre-regulation to minimize conducted noise on the input and provide a predictable switching frequency. The switching frequency is programmable to 725 kHz, 300 kHz, 37 kHz, or 9.5 kHz.

LM2751 Typical Application Circuit



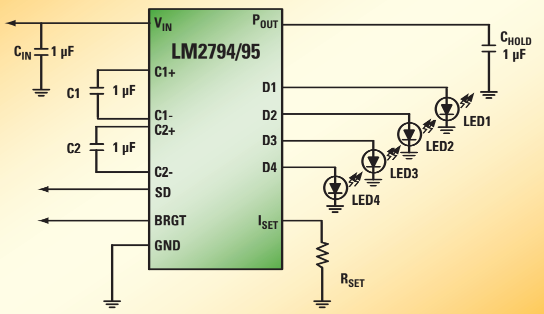
Low-Voltage LED Lighting

LM2794/95 Current-Regulated Switched-Capacitor LED Supply with Analog and PWM Brightness Control

Theory of Operation

The LM2794/95 are fractional CMOS charge pumps that provide four regulated current sources. They accept an input voltage range from 2.7V to 5.5V and maintain a constant current determined by an external sense resistor. The LM2794/95 deliver up to 80 mA of load current to accommodate four white LEDs. The switching frequency is 325 kHz (min) to keep the conducted noise spectrum away from sensitive frequencies within portable RF devices.

LM2794/95 Typical Application Circuit

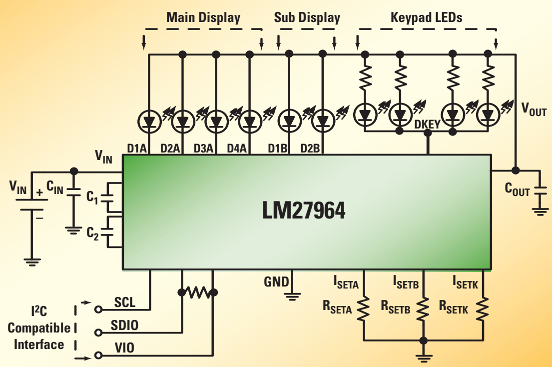


LM27964 Dual-Display + Keypad White-LED Drivers with 3/2x Switched-Capacitor Boost and I²C-Compatible Brightness Control

Theory of Operation

The LM27964 is a charge pump-based white-LED driver that is ideal for display backlighting. It can drive up to eight LEDs in parallel with up to 20 mA through each LED, along with multiple keypad LEDs. Regulated internal current sources deliver excellent current- and brightness-matching in all LEDs. The LED driver's current sources are split into two independently controlled groups.

LM27964 Typical Application Circuit



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.

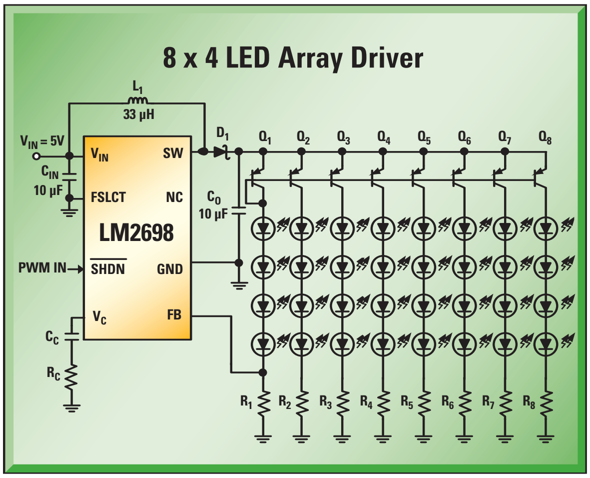
For these cases, a regulator is needed that can both buck and boost the output as needed. Possible topologies include the buck-boost regulator, the SEPIC regulator, the Cuk regulator, and the flyback regulator. In all of these topologies the power-switch current exceeds the LED current and varies as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

High-Brightness LED Lighting

LM2698 SIMPLE SWITCHER® 1.35A Boost Regulator

Theory of Operation

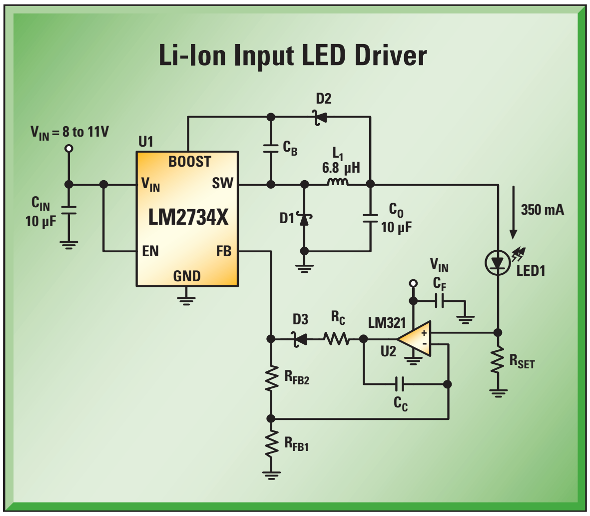
This circuit consists of a power section optimized to deliver a total of 160 mA to the LED array. The first string is controlled by the feedback loop to 20 mA. The remaining strings are controlled by the current mirrors at the top of each string.



LM2734 1A Step-Down Buck Regulator

Theory of Operation

As shown, this design will begin to regulate the output current as soon as it has input voltage. It will run in a dropout mode for V_{IN} below (V_F + 0.8V) and will not operate for V_{IN} below 3.0V.

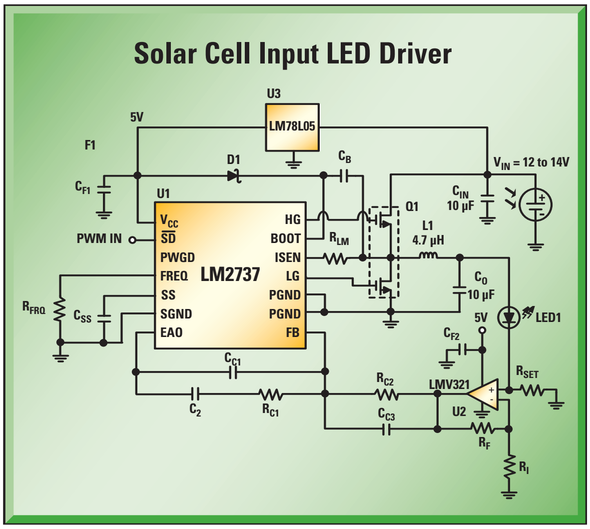


LM2737 Synchronous NFET Buck Controller

Theory of Operation

This circuit delivers a constant current of 2A to a multi-die IR LED device. The solar-cell input requires very high efficiency, and a synchronous buck controller allows the use of a small FET at high frequency (800 kHz) to achieve that efficiency. The LM78L05 provides a simple 5V rail for both the logic and FET drive of the LM2737 and the LMV321.

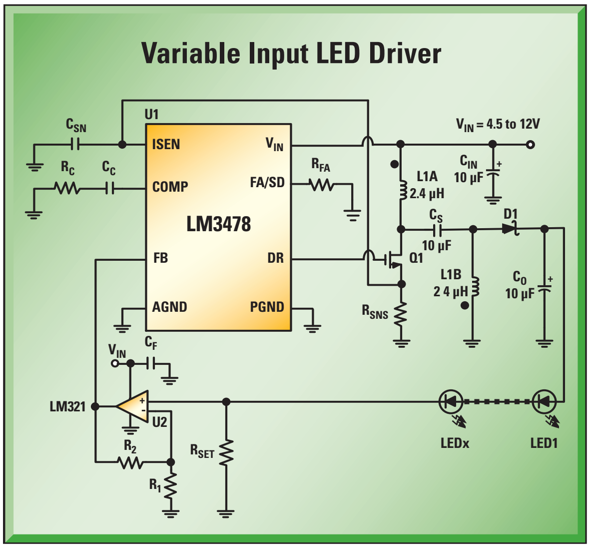
The LM2737 is especially well-suited to the PWM dimming because the LM2737 discharges the output through the bottom power FET when disabled.



LM3478 Low-Side NFET Controller

Theory of Operation

This circuit can deliver a constant current of 350 mA to an array of 2 to 8 LEDs over a wide range of input voltages. This SEPIC design can buck or boost the output voltage, with a designed output voltage range of 6.5V to 30V. The SEPIC design also means that the number and type of LEDs can vary.



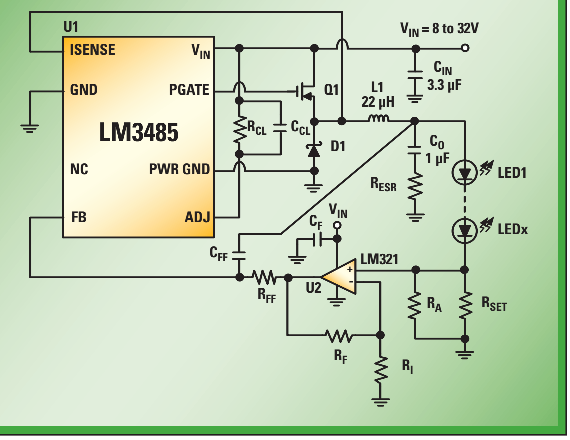
High-Brightness LED Lighting

LM3485 Hysteretic PFET Buck Controller

Theory of Operation

This circuit is designed to drive an array of high-brightness LEDs from a wide range of input voltages at 350 mA.

Wide Input Range LED Driver

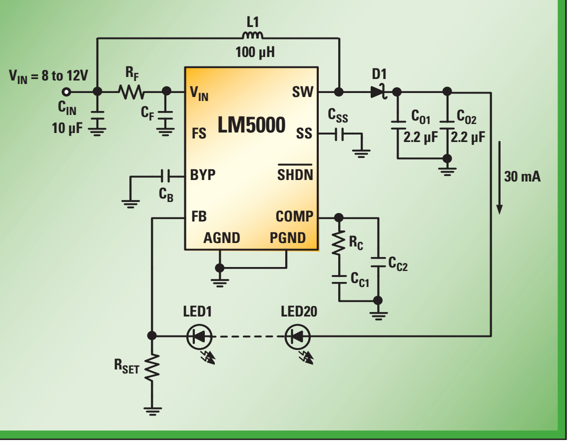


LM5000 High-Voltage Boost Regulator

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.

Vanity Mirror LED Backlight

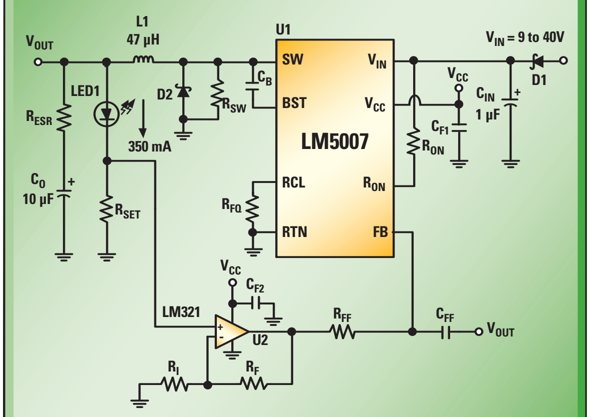


LM5007 High-Voltage Buck Regulator

Theory of Operation

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). It operates at approximately 600 kHz, and regulates the current in the LED at 350 mA from inputs of 8V to 40V. This makes it suitable for standard passenger cars and trucks with 8V to 16V batteries as well as freight trucks, tow trucks, fork lifts, and other vehicles that use a double lead-acid battery system (16V to 32V). Diode D1 provides reverse battery protection, and the LM5007 can withstand input voltages up to 75V. This circuit does not need additional protection from 'load dump.'

Automotive LED Tail Light

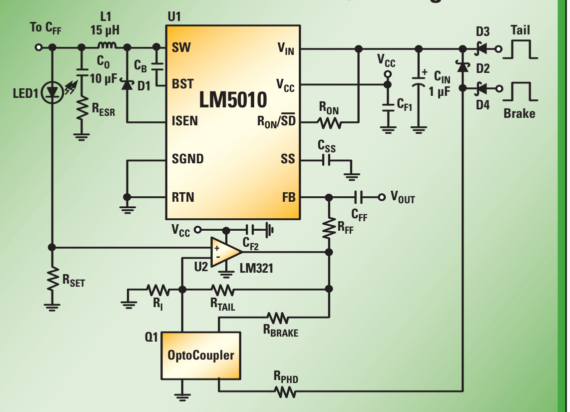


LM5010 High-Voltage 1A Buck Regulator

Theory of Operation

This circuit is designed to replace a dual-filament incandescent bulb in a combined brake/tail light for automotive use. 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 to 16V batteries as well as freight trucks, tow trucks, fork lifts, and other vehicles that use a double lead-acid battery system, or 16V to 32V. Diodes D3 and D4 provide reverse battery protection, and D2 ensures that a brake input supercedes a tail input. The LM5010 can withstand input voltages of up to 75V. This circuit does not need additional protection from 'load dump.'

Automotive LED Brake/Tail Light



High Integration LED Drivers and Color LED Drivers

Lighting Management Units (LMUs) are single ICs for mobile lighting including LED drivers for display, indicator, RGB, keypad, and flash. The advantages of LMUs are small solution size, high efficiency, easy control, and flexibility.

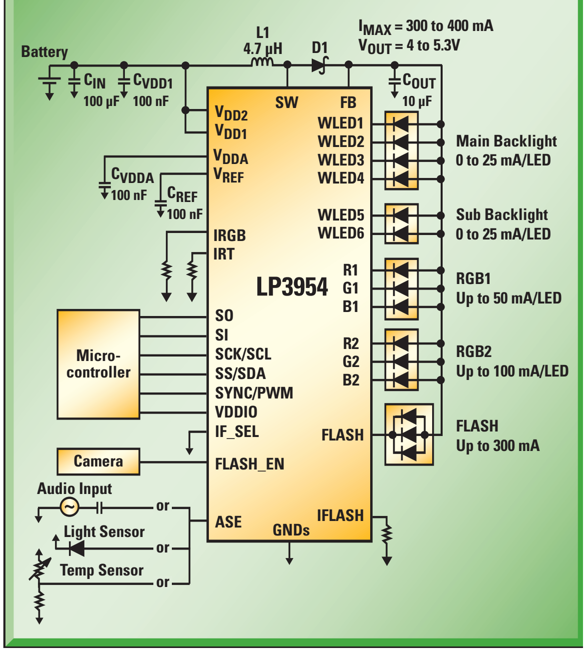
Product ID	Description	V_{IN} Range	Key Functions	Drive Current for All	Packaging
LP3931	Lighting management unit for independently controlling 2 RGB LEDs or 6 color/white LEDs, SPI interface	3 to 7	Boost switching regulator; 2x RGB LED drivers with programmable color, brightness, turn on/off slopes and blinking patterns	120 mA per LED (6x)	LLP-24
LP3933	Lighting management unit for controlling 4+2 x WLEDs and 2x RGB fun-light LEDs	3 to 6	Boost switching regulator, 6x WLEDs, programmable display LED current control, 2x RGB with full programmability, SPI interface	WLEDs 25 mA per LED, RGB 100 mA per LED	CSP-32
LP3936	Lighting management unit for controlling 4+2 x WLEDs and 1x RGB fun-light LED, ambient light sensor ADC	3 to 6	Boost switching regulator, 6x WLEDs, 1x RGB, ambient light sensor with averaging, I^2C/Microwire/SPI interface	WLEDs 25 mA per LED, RGB 100 mA per LED	CSP-32
LP3944	LED controller for RGB/color/white LEDs with I^2C	3 to 5	Eight LED drivers with programmable on/off, timing and brightness control, I^2C, GPIO functionality	RGBs up to 25 mA/LED	LLP-24
LP3950	Audio synchronization color/RGB LED driver, with I^2C/SPI interface	3 to 6	Boost switching regulator, two programmable RGB outputs, built-in audio synchronization modes	RGBs up to 25 mA/LED	CSP-32
LP3954	Complete lighting management unit for cell phones and other portable devices	3 to 6	Boost switching regulator, 6x WLEDs, 2x RGB with built-in stand alone controller, ambient light sensor with averaging, audio synchronization, I^2C/SPI interface	WLED 25 mA per LED, RGBs up to 50 mA/LED, Flash 300 mA	micro SMD-36

LP3954 Advanced Lighting Management Unit

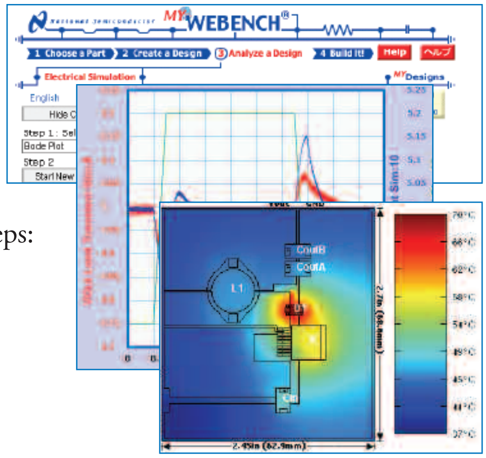
Theory of Operation

LP3954 is an advanced LMU for handheld devices. The boost DC-DC drives high-current loads with high efficiency. Backlight drivers and the stand-alone command-based RGB controller are feature rich and easy to configure. The built-in audio synchronization feature allows users to synchronize the color LEDs to audio inputs. The integrated single driver can drive a high-current camera flash LED or motor/vibra. The internal ADC can be also used for ambient light or temperature sensing. The flexible interface (SPI/I^2C) allows the easy control of LP3954. The small micro SMD package together with minimum external components is an ideal fit for handheld devices.

LP3954 Typical Application



WEBENCH® Online Design Environment



Use this online design and prototyping environment to accelerate your design process in just four simple steps:

1. Choose a part
2. Create a design
3. Analyze it using electrical and thermal simulation
4. Build it with your custom kit that is delivered 24 hours later

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Application Notes

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- **Switched-Capacitor Converters**
  - AN-1187 Leadless Leadframe Package (LLP)
  - AN-1251 Switched Capacitor Circuits Provide Efficient and Functional White-LED Drive
- **Inductive-Boost Regulators**
  - AN-556 Introduction to Power Supplies
  - AN-1149 Layout Guidelines for Switching Power Supplies
  - AN-1246 Stresses in Wide Input DC-DC Converters
  - AN-1250 Inductive-Boost Switching-Regulator Circuits Provide High-Efficiency White-LED Drives

For More Information

National Semiconductor provides a comprehensive set of support services. Product information, including sales literature and technical assistance, is available through National's Customer Support Centers.
For more information on lighting solutions visit:
www.national.com/lighting

Americas
Email: new.feedback@nsc.com
Phone: 1-800-272-9959

Europe
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Phone: Deutsch + 49 (0) 69 9508 6208
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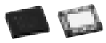
Phone: 81-3-5639-7560

Packaging Solutions

AVAILABLE LEAD-FREE

θ_{JA} shown are typical


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


SOIC
θ_{JA} 100 to 190°C/W

micro SMD
θ_{JA} 220 °C/W


SOT-23
θ_{JA} 240 °C/W

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