November 17, 2011

LM3444

AC-DC Offline LED Driver

General Description

The LM3444 is an adaptive constant off-time AC/DC buck (step-down) constant current controller that provides a constant current for illuminating high power LEDs. The high frequency capable architecture allows the use of small external passive components. A passive PFC circuit ensures good power factor by drawing current directly from the line for most of the cycle, and provides a constant positive voltage to the buck regulator. Additional features include thermal shutdown, current limit and V_{CC} under-voltage lockout. The LM3444 is available in a low profile MSOP-10 package or an 8 lead SOIC package.

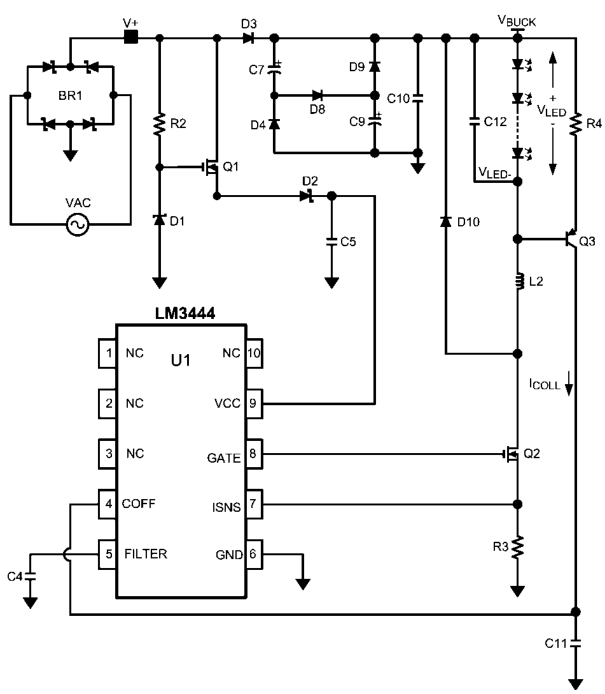
Features

- Application voltage range $80V_{AC}$ – $277V_{AC}$
- Capable of controlling LED currents greater than 1A
- Adjustable switching frequency
- Low quiescent current
- Adaptive programmable off-time allows for constant ripple current
- Thermal shutdown
- No 120Hz flicker
- Low profile 10 pin MSOP package or 8 lead SOIC package
- Patent pending drive architecture

Applications

- Solid State Lighting
- Industrial and Commercial Lighting
- Residential Lighting

Typical LM3444 LED Driver Application Circuit



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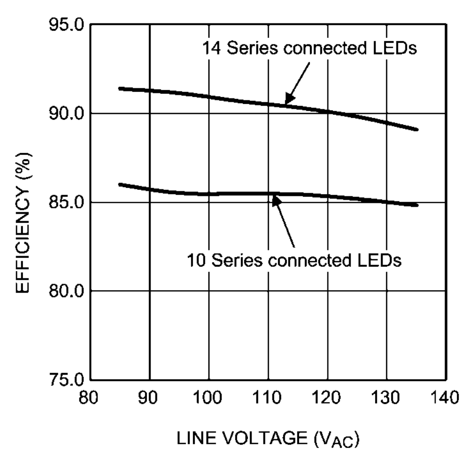

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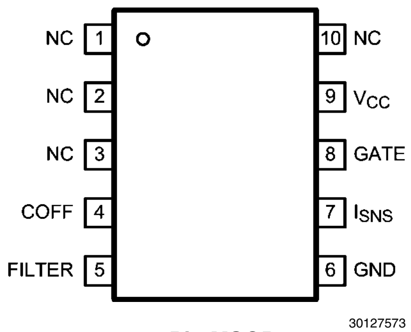
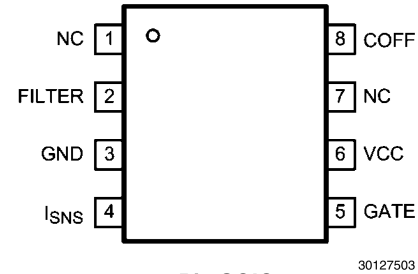
Connection Diagrams



10-Pin MSOP
NS Package Number MUB10A



8-Pin SOIC
NS Package Number M08A

Ordering Information

Order Number	Spec.	Package Type	NSC Package Drawing	Top Mark	Supplied As
LM3444MM	NOPB	MSOP-10	MUB10A	SZTB	1000 Units, Tape and Reel
LM3444MMX	NOPB	MSOP-10	MUB10A	SZTB	3500 Units, Tape and Reel
LM3444MA	NOPB	SOIC-8	M08A	LM3444MA	95 Units, Rail
LM3444MAX	NOPB	SOIC-8	M08A	LM3444MA	2500 Units, Tape and Reel

Pin Descriptions

MSOP	SOIC	Name	Description
1	1	NC	No internal connection. Leave this pin open.
2		NC	No internal connection. Leave this pin open.
3		NC	No internal connection. Leave this pin open.
4	8	COFF	OFF time setting pin. A user set current and capacitor connected from the output to this pin sets the constant OFF time of the switching controller.
5	2	FILTER	Filter input. A low pass filter tied to this pin can filter a PWM dimming signal to supply a DC voltage to control the LED current. Can also be used as an analog dimming input. If not used for dimming connect a 0.1µF capacitor from this pin to ground.
6	3	GND	Circuit ground connection.
7	4	ISNS	LED current sense pin. Connect a resistor from main switching MOSFET source, ISNS to GND to set the maximum LED current.
8	5	GATE	Power MOSFET driver pin. This output provides the gate drive for the power switching MOSFET of the buck controller.
9	6	V_{CC}	Input voltage pin. This pin provides the power for the internal control circuitry and gate driver.
10	7	NC	No internal connection. Leave this pin open.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.

V_{CC} and GATE to GND	-0.3V to +14V
ISNS to GND	-0.3V to +2.5V
FILTER and COFF to GND	-0.3V to +7.0V
COFF Input Current	60mA
Continuous Power Dissipation (Note 2)	Internally Limited
ESD Susceptibility	
HBM (Note 3)	2 kV
Junction Temperature ($T_{J\text{-}MAX}$)	150°C
Storage Temperature Range	-65°C to +150°C
Maximum Lead Temp. Range (Soldering)	260°C

Operating Conditions

V_{CC}	8.0V to 13V
Junction Temperature	–40°C to +125°C

Electrical Characteristics

Limits in standard type face are for T_J = 25°C and those with **boldface type** apply over the full **Operating Temperature Range** (T_J = –40°C to +125°C). Minimum and Maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at T_J = +25ºC, and are provided for reference purposes only. Unless otherwise stated the following conditions apply: V_{CC} = 12V.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{CC} SUPPLY						
I_{VCC}	Operating supply current			1.58	**2.25**	mA
$V_{CC\text{-}UVLO}$	Rising threshold			7.4	**7.7**	V
	Falling threshold		**6.0**	6.4		
	Hysterisis			1		
COFF						
V_{COFF}	Time out threshold		**1.225**	1.276	**1.327**	V
R_{COFF}	Off timer sinking impedance			33	**60**	Ω
t_{COFF}	Restart timer			180		µs
CURRENT LIMIT						
V_{ISNS}	ISNS limit threshold		**1.174**	1.269	**1.364**	V
t_{ISNS}	Leading edge blanking time			125		ns
	Current limit reset delay			180		µs
	ISNS limit to GATE delay	ISNS = 0 to 1.75V step		33		ns
CURRENT SENSE COMPARATOR						
V_{FILTER}	FILTER open circuit voltage		**720**	750	**780**	mV
R_{FILTER}	FILTER impedance			1.12		MΩ
V_{OS}	Current sense comparator offset voltage		**-4.0**	0.1	**4.0**	mV
GATE DRIVE OUTPUT						
V_{DRVH}	GATE high saturation	I_{GATE} = 50 mA		0.24	**0.50**	V
V_{DRVL}	GATE low saturation	I_{GATE} = 100 mA		0.22	**0.50**	
I_{DRV}	Peak souce current	GATE = $V_{CC}/2$		-0.77		A
	Peak sink current	GATE = $V_{CC}/2$		0.88		
t_{DV}	Rise time	C_{load} = 1 nF		15		ns
	Fall time	C_{load} = 1 nF		15		
THERMAL SHUTDOWN						
T_{SD}	Thermal shutdown temperature	(Note 4)		165		°C
	Thermal shutdown hysteresis			20		
THERMAL SPECIFICATION						
$R_{θJA}$	MSOP-10 junction to ambient			124		°C/W
$R_{θJC}$	MSOP-10 junction to case			76		

Note 1: Absolute maximum ratings are limits beyond which damage to the device may occur. Operating Ratings are conditions for which the device is intended to be functional, but device parameter specifications may not be guaranteed. For guaranteed specifications and test conditions, see the Electrical Characteristics. All voltages are with respect to the potential at the GND pin, unless otherwise specified.

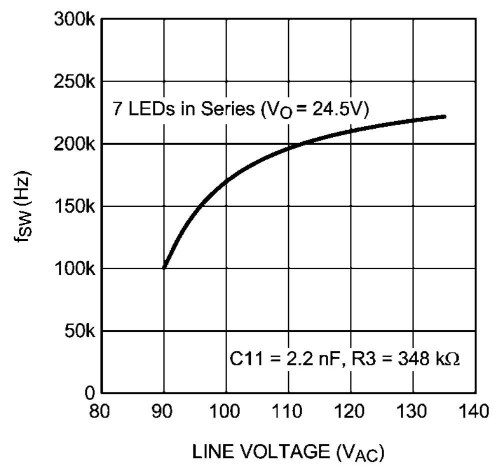
Note 2: Internal thermal shutdown circuitry protects the device from permanent damage. Thermal shutdown engages at T_J = 165°C (typ.) and disengages at T_J = 145°C (typ).

Note 3: Human Body Model, applicable std. JESD22-A114-C.

Note 4: Junction-to-ambient thermal resistance is highly application and board-layout dependent. In applications where high maximum power dissipation exists, special care must be paid to thermal dissipation issues in board design. In applications where high power dissipation and/or poor package thermal resistance is present, the maximum ambient temperature may have to be derated. Maximum ambient temperature ($T_{A\text{-}MAX}$) is dependent on the maximum operating junction temperature ($T_{J\text{-}MAX\text{-}OP}$ = 125°C), the maximum power dissipation of the device in the application ($P_{D\text{-}MAX}$), and the junction-to ambient thermal resistance of the part/package in the application ($R_{\theta JA}$), as given by the following equation: $T_{A\text{-}MAX} = T_{J\text{-}MAX\text{-}OP} - (R_{\theta JA} \times P_{D\text{-}MAX})$.

Typical Performance Characteristics

f_{SW} vs Input Line Voltage



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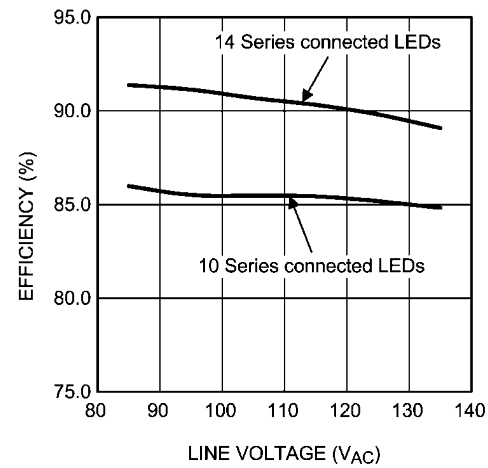
Efficiency vs Input Line Voltage



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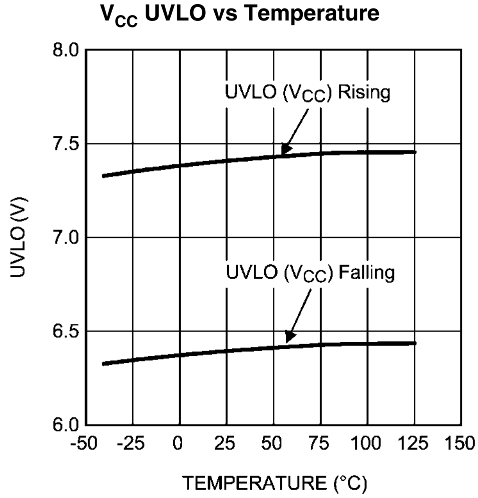
V_{CC} UVLO vs Temperature



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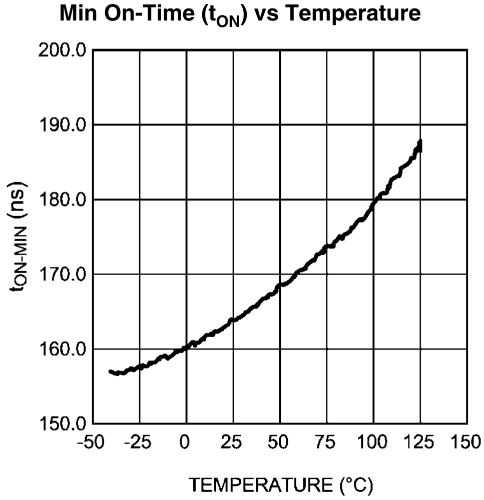
Min On-Time (t_{ON}) vs Temperature



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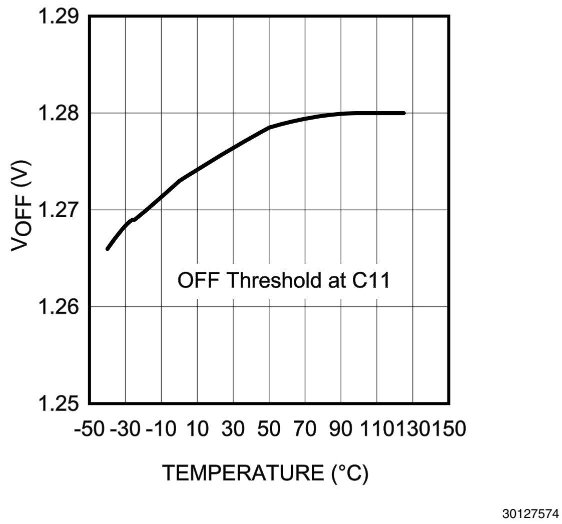
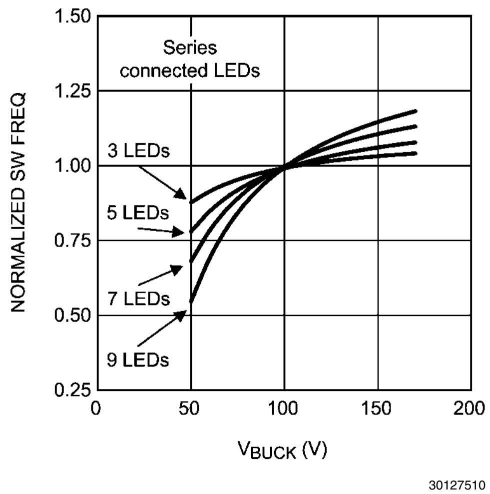
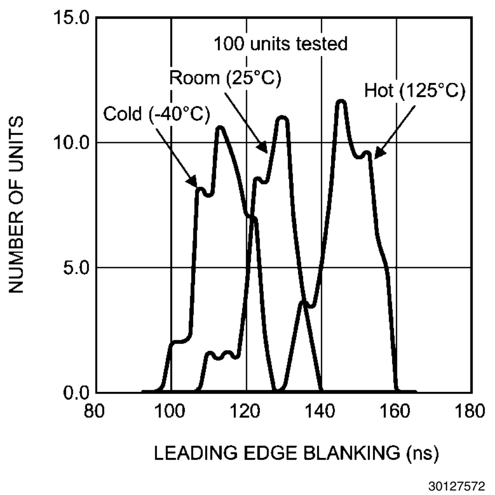
Off Threshold (C11) vs Temperature



Normalized Variation in f_{SW} over V_{BUCK} Voltage



Leading Edge Blanking Variation Over Temperature



Simplified Internal Block Diagram

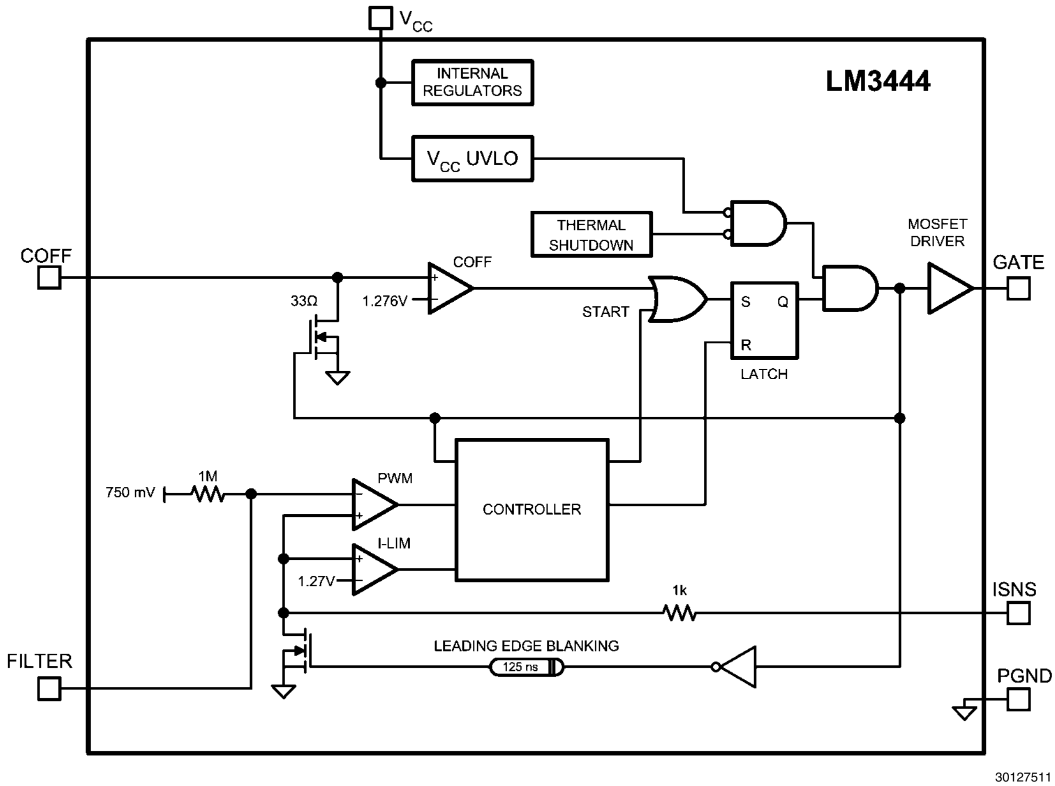


FIGURE 1. Simplified Block Diagram

Application Information

FUNCTIONAL DESCRIPTION

The LM3444 contains all the necessary circuitry to build a line-powered (mains powered) constant current LED driver.

Theory of Operation

Refer to *Figure 2* below which shows the LM3444 along with basic external circuitry.

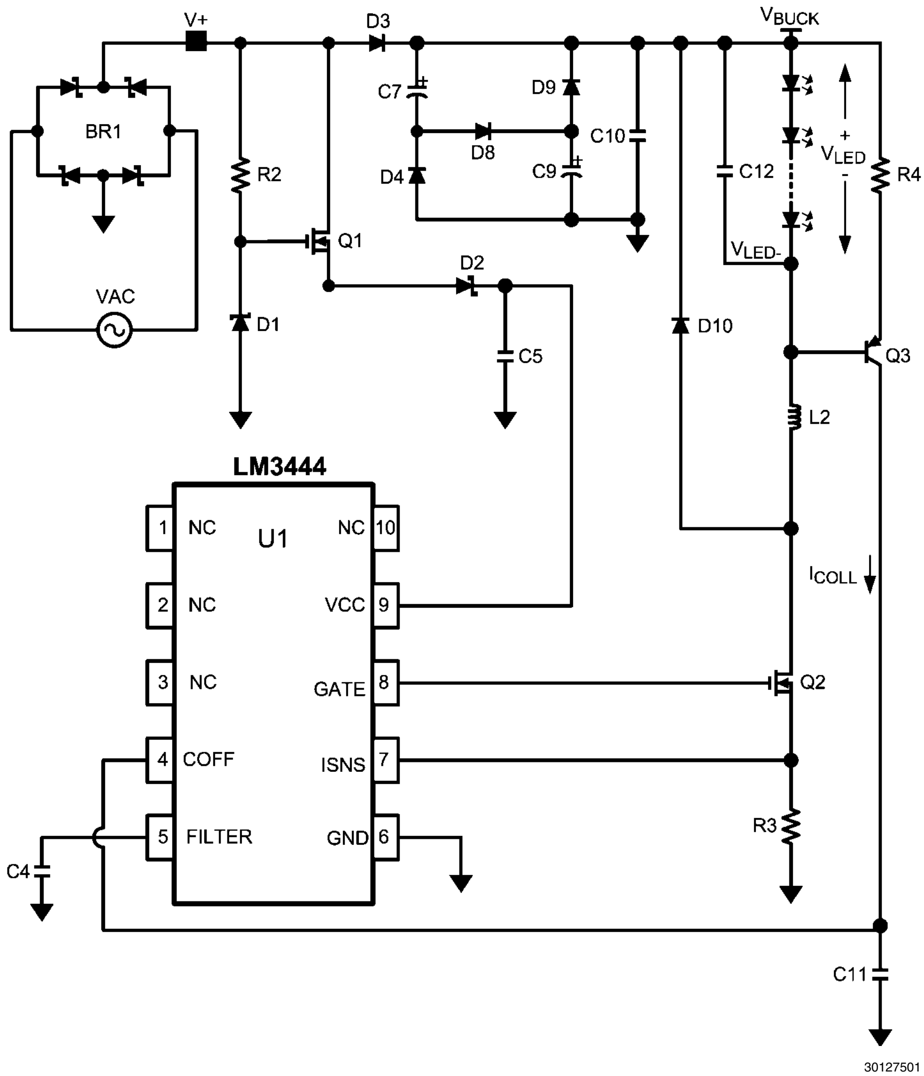


FIGURE 2. LM3444 Schematic

VALLEY-FILL CIRCUIT

V_{BUCK} supplies the power which drives the LED string. Diode D3 allows V_{BUCK} to remain high while V+ cycles on and off. V_{BUCK} has a relatively small hold capacitor C10 which reduces the voltage ripple when the valley fill capacitors are being charged. However, the network of diodes and capacitors shown between D3 and C10 make up a "valley-fill" circuit. The valley-fill circuit can be configured with two or three stages. The most common configuration is two stages. *Figure 3* illustrates a two and three stage valley-fill circuit.

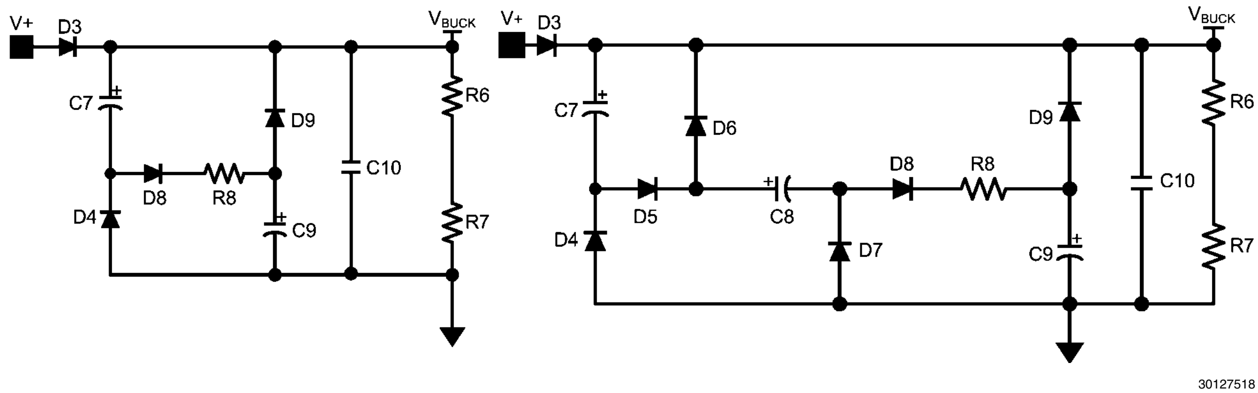


FIGURE 3. Two and Three Stage Valley Fill Circuit

The valley-fill circuit allows the buck regulator to draw power throughout a larger portion of the AC line. This allows the capacitance needed at V_{BUCK} to be lower than if there were no valley-fill circuit, and adds passive power factor correction (PFC) to the application.

VALLEY-FILL OPERATION

When the “input line is high”, power is derived directly through D3. The term “input line is high” can be explained as follows. The valley-fill circuit charges capacitors C7 and C9 in series (*Figure 4*) when the input line is high.

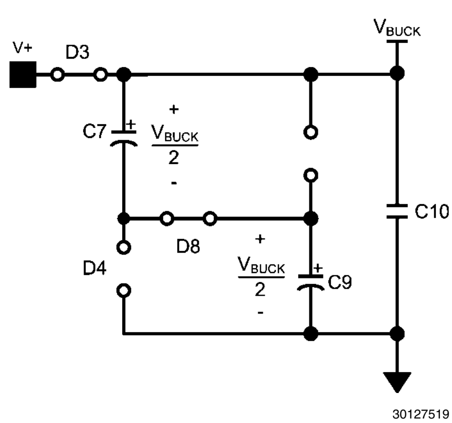


FIGURE 4. Two stage Valley-Fill Circuit when AC Line is High

The peak voltage of a two stage valley-fill capacitor is:

$$V_{VF\text{-}CAP} = \frac{V_{AC\text{-}RMS}\sqrt{2}}{2}$$

As the AC line decreases from its peak value every cycle, there will be a point where the voltage magnitude of the AC line is equal to the voltage that each capacitor is charged. At this point diode D3 becomes reversed biased, and the capacitors are placed in parallel to each other (*Figure 5*), and V_{BUCK} equals the capacitor voltage.

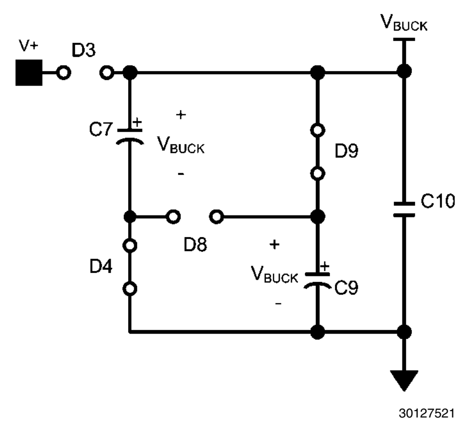


FIGURE 5. Two stage Valley-Fill Circuit when AC Line is Low

A three stage valley-fill circuit performs exactly the same as two-stage valley-fill circuit except now three capacitors are now charged in series, and when the line voltage decreases to:

$$V_{VF\text{-}CAP} = \frac{V_{AC\text{-}RMS}\sqrt{2}}{3}$$

Diode D3 is reversed biased and three capacitors are in parallel to each other.

The valley-fill circuit can be optimized for power factor, voltage hold up and overall application size and cost. The LM3444 will operate with a single stage or a three stage valley-fill circuit as well. Resistor R8 functions as a current limiting resistor during start-up, and during the transition from series to parallel connection. Resistors R6 and R7 are 1 MΩ bleeder resistors, and may or may not be necessary for each application.

BUCK CONVERTER

The LM3444 is a buck controller that uses a proprietary constant off-time method to maintain constant current through a string of LEDs. While transistor Q2 is on, current ramps up through the inductor and LED string. A resistor R3 senses this current and this voltage is compared to the reference voltage at FILTER. When this sensed voltage is equal to the reference voltage, transistor Q2 is turned off and diode D10 conducts the current through the inductor and LEDs. Capacitor C12 eliminates most of the ripple current seen in the inductor. Resistor R4, capacitor C11, and transistor Q3 provide a linear current ramp that sets the constant off-time for a given output voltage.

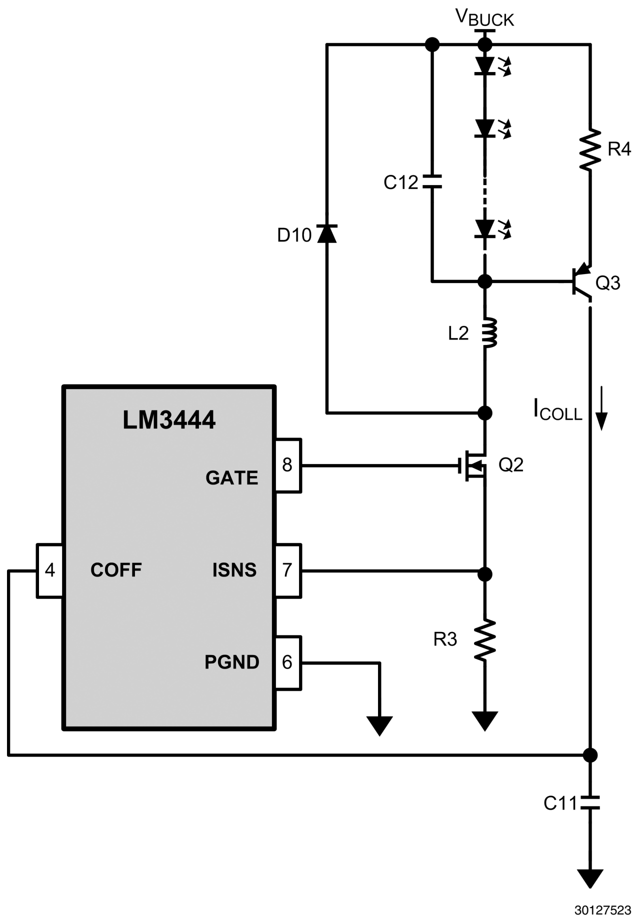


FIGURE 6. LM3444 Buck Regulation Circuit

OVERVIEW OF CONSTANT OFF-TIME CONTROL

A buck converter's conversion ratio is defined as:

$$\frac{V_O}{V_{IN}} = D = \frac{t_{ON}}{t_{ON} + t_{OFF}} = t_{ON} \times f_{SW}$$

Constant off-time control architecture operates by simply defining the off-time and allowing the on-time, and therefore the switching frequency, to vary as either V_{IN} or V_O changes. The output voltage is equal to the LED string voltage (V_{LED}), and should not change significantly for a given application. The input voltage or V_{BUCK} in this analysis will vary as the input line varies. The length of the on-time is determined by the sensed inductor current through a resistor to a voltage reference at a comparator. During the on-time, denoted by t_{ON}, MOSFET switch Q2 is on causing the inductor current to increase. During the on-time, current flows from V_{BUCK}, through the LEDs, through L2, Q2, and finally through R3 to ground. At some point in time, the inductor current reaches a maximum ($I_{L2\text{-}PK}$) determined by the voltage sensed at R3 and the ISNS pin. This sensed voltage across R3 is compared against the voltage of FILTER, at which point Q2 is turned off by the controller.

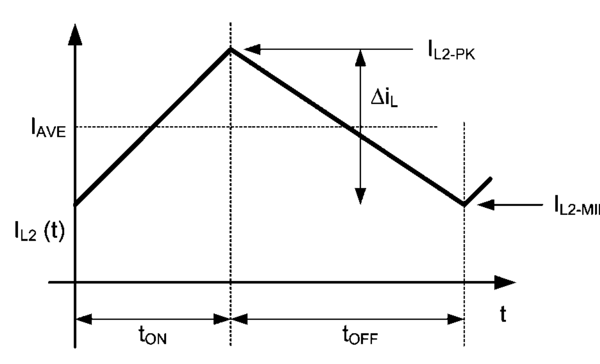


FIGURE 7. Inductor Current Waveform in CCM

During the off-period denoted by t_{OFF}, the current through L2 continues to flow through the LEDs via D10.

THERMAL SHUTDOWN

Thermal shutdown limits total power dissipation by turning off the output switch when the IC junction temperature exceeds 165°C. After thermal shutdown occurs, the output switch doesn't turn on until the junction temperature drops to approximately 145°C.

Design Guide

DETERMINING DUTY-CYCLE (D)

Duty cycle (D) approximately equals:

$$\frac{V_{LED}}{V_{BUCK}} = D = \frac{t_{ON}}{t_{ON} + t_{OFF}} = t_{ON} \times f_{SW}$$

With efficiency considered:

$$\frac{1}{\eta} \times \frac{V_{LED}}{V_{BUCK}} = D$$

For simplicity, choose efficiency between 75% and 85%.

CALCULATING OFF-TIME

The "Off-Time" of the LM3444 is set by the user and remains fairly constant as long as the voltage of the LED stack remains constant. Calculating the off-time is the first step in determining the switching frequency of the converter, which is integral in determining some external component values.

PNP transistor Q3, resistor R4, and the LED string voltage define a charging current into capacitor C11. A constant current into a capacitor creates a linear charging characteristic.

$$i = C\frac{dv}{dt}$$

Resistor R4, capacitor C11 and the current through resistor R4 (i_{COLL}), which is approximately equal to V_{LED}/R4, are all fixed. Therefore, dv is fixed and linear, and dt (t_{OFF}) can now be calculated.

$$t_{OFF} = C11 \times 1.276V \times \left(\frac{R4}{V_{LED}}\right)$$

Common equations for determining duty cycle and switching frequency in any buck converter:

$$f_{SW} = \frac{1}{t_{OFF} + t_{ON}}$$

$$D = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{V_{LED}}{V_{BUCK}}$$

$$D' = \frac{t_{OFF}}{t_{ON} + t_{OFF}}$$

Therefore:

$$f_{SW} = \frac{D}{t_{ON}}, \text{ and } f_{SW} = \frac{1 - D}{t_{OFF}}$$

With efficiency of the buck converter in mind:

$$\frac{V_{LED}}{V_{BUCK}} = \eta \times D$$

Substitute equations and rearrange:

$$f_{SW} = \frac{\left(1 - \frac{1}{\eta} \times \frac{V_{LED}}{V_{BUCK}}\right)}{t_{OFF}}$$

Off-time, and switching frequency can now be calculated using the equations above.

SETTING THE SWITCHING FREQUENCY

Selecting the switching frequency for nominal operating conditions is based on tradeoffs between efficiency (better at low frequency) and solution size/cost (smaller at high frequency).

The input voltage to the buck converter (V_{BUCK}) changes with both line variations and over the course of each half-cycle of the input line voltage. The voltage across the LED string will, however, remain constant, and therefore the off-time remains constant.

The on-time, and therefore the switching frequency, will vary as the V_{BUCK} voltage changes with line voltage. A good design practice is to choose a desired nominal switching frequency knowing that the switching frequency will decrease as the line voltage drops and increase as the line voltage increases (*Figure 8*).

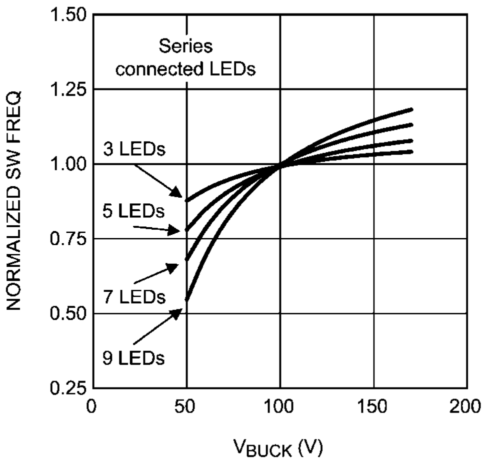


FIGURE 8. Graphical Illustration of Switching Frequency vs V_{BUCK}

The off-time of the LM3444 can be programmed for switching frequencies ranging from 30 kHz to over 1 MHz. A trade-off between efficiency and solution size must be considered when designing the LM3444 application.

The maximum switching frequency attainable is limited only by the minimum on-time requirement (200 ns).

Worst case scenario for minimum on time is when V_{BUCK} is at its maximum voltage (AC high line) and the LED string voltage (V_{LED}) is at its minimum value.

$$t_{ON(MIN)} = \left(\frac{1}{\eta} \times \frac{V_{LED(MIN)}}{V_{BUCK(MAX)}}\right)\frac{1}{f_{SW}}$$

The maximum voltage seen by the Buck Converter is:

$$V_{BUCK(MAX)} = V_{AC\text{-}RMS(MAX)} \times \sqrt{2}$$

INDUCTOR SELECTION

The controlled off-time architecture of the LM3444 regulates the average current through the inductor (L2), and therefore the LED string current. The input voltage to the buck converter (V_{BUCK}) changes with line variations and over the course of each half-cycle of the input line voltage. The voltage across the LED string is relatively constant, and therefore the current through R4 is constant. This current sets the off-time of the converter and therefore the output volt-second product (V_{LED} x off-time) remains constant. A constant volt-second product makes it possible to keep the ripple through the inductor constant as the voltage at V_{BUCK} varies.

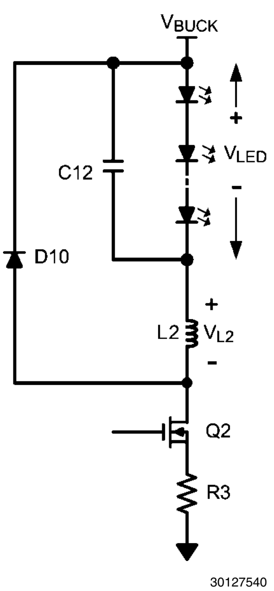


FIGURE 9. LM3444 External Components of the Buck Converter

The equation for an ideal inductor is:

$$v = L\frac{di}{dt}$$

Given a fixed inductor value, L, this equation states that the change in the inductor current over time is proportional to the voltage applied across the inductor.

During the on-time, the voltage applied across the inductor is,

$$V_{L(ON\text{-}TIME)} = V_{BUCK} - (V_{LED} + V_{DS(Q2)} + I_{L2} \times R3)$$

Since the voltage across the MOSFET switch (Q2) is relatively small, as is the voltage across sense resistor R3, we can simplify this to approximately,

$$V_{L(ON\text{-}TIME)} = V_{BUCK} - V_{LED}$$

During the off-time, the voltage seen by the inductor is approximately:

$$V_{L(OFF\text{-}TIME)} = V_{LED}$$

The value of $V_{L(OFF\text{-}TIME)}$ will be relatively constant, because the LED stack voltage will remain constant. If we rewrite the equation for an inductor inserting what we know about the circuit during the off-time, we get:

$$V_{L(OFF\text{-}TIME)} = V_{LED} = L \times \frac{\Delta i}{\Delta t}$$

$$V_{L(OFF\text{-}TIME)} = V_{LED} = L \times \frac{(I_{(MAX)} - I_{(MIN)})}{\Delta t}$$

Re-arranging this gives:

$$\Delta i \cong t_{OFF} \times \frac{V_{LED}}{L2}$$

From this we can see that the ripple current (Δi) is proportional to off-time (t_{OFF}) multiplied by a voltage which is dominated by V_{LED} divided by a constant (L2).

These equations can be rearranged to calculate the desired value for inductor L2.

$$L2 \cong t_{OFF} \times \frac{V_{LED}}{\Delta i}$$

Where:

$$t_{OFF} = \frac{\left(1 - \frac{1}{\eta} \times \frac{V_{LED}}{V_{BUCK}}\right)}{f_{SW}}$$

Finally:

$$L2 = \frac{V_{LED}\left(1 - \frac{1}{\eta} \times \frac{V_{LED}}{V_{BUCK}}\right)}{f_{SW} \times \Delta i}$$

Refer to "Design Example" section of the datasheet to better understand the design process.

SETTING THE LED CURRENT

The LM3444 constant off-time control loop regulates the peak inductor current (I_{L2}). The average inductor current equals the average LED current (I_{AVE}). Therefore the average LED current is regulated by regulating the peak inductor current.

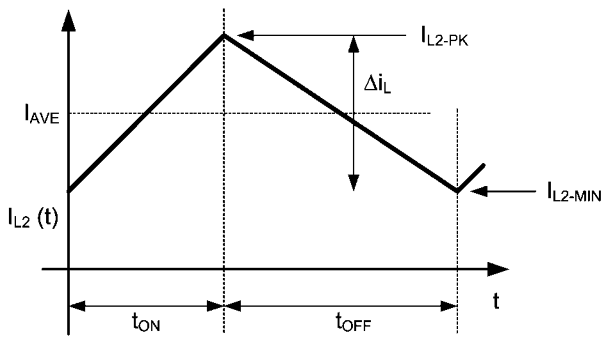


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FIGURE 10. Inductor Current Waveform in CCM

Knowing the desired average LED current, I_{AVE} and the nominal inductor current ripple, Δi_L, the peak current for an application running in continuous conduction mode (CCM) is defined as follows:

$$I_{L2\text{-}PK} = I_{AVE} + \frac{\Delta i_L}{2}$$

Or the LED current would then be,

$$I_{AVE(UNDIM)} = I_{L2\text{-}PK(UNDIM)} - \frac{\Delta i_L}{2}$$

This is important to calculate because this peak current multiplied by the sense resistor R3 will determine when the internal comparator is tripped. The internal comparator turns the control MOSFET off once the peak sensed voltage reaches 750 mV.

$$I_{L\text{-}PK(UNDIM)} = \frac{750\text{ mV}}{R3}$$

Current Limit: The trip voltage on the PWM comparator is 750 mV. However, if there is a short circuit or an excessive load on the output, higher than normal switch currents will cause a voltage above 1.27V on the ISNS pin which will trip the I-LIM comparator. The I-LIM comparator will reset the RS latch, turning off Q2. It will also inhibit the Start Pulse Generator and the COFF comparator by holding the COFF pin low. A delay circuit will prevent the start of another cycle for 180 µs.

VALLEY FILL CAPACITORS

Determining voltage rating and capacitance value of the valley-fill capacitors:

The maximum voltage seen by the valley-fill capacitors is:

$$V_{VF\text{-}CAP} = \frac{V_{AC(MAX)}\sqrt{2}}{\#stages}$$

This is, of course, if the capacitors chosen have identical capacitance values and split the line voltage equally. Often a 20% difference in capacitance could be observed between like capacitors. Therefore a voltage rating margin of 25% to 50% should be considered.

Determining the capacitance value of the valley-fill capacitors:

The valley fill capacitors should be sized to supply energy to the buck converter (V_{BUCK}) when the input line is less than its peak divided by the number of stages used in the valley fill (t_X). The capacitance value should be calculated for the maximum LED current.

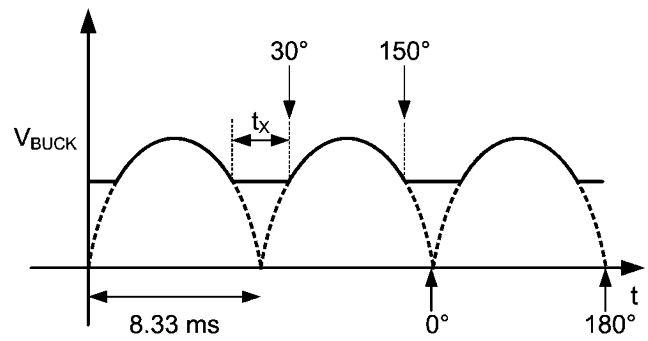

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FIGURE 11. Two Stage Valley-Ffill V_{BUCK} Voltage

From the above illustration and the equation for current in a capacitor, i = C x dV/dt, the amount of capacitance needed at V_{BUCK} will be calculated as follows:

At 60Hz, and a valley-fill circuit of two stages, the hold up time (t_X) required at V_{BUCK} is calculated as follows. The total angle of an AC half cycle is 180° and the total time of a half AC line cycle is 8.33 ms. When the angle of the AC waveform is at 30° and 150°, the voltage of the AC line is exactly ½ of its peak. With a two stage valley-fill circuit, this is the point where the LED string switches from power being derived from AC line to power being derived from the hold up capacitors (C7 and C9). 60° out of 180° of the cycle or 1/3 of the cycle the power is derived from the hold up capacitors (1/3 x 8.33 ms = 2.78 ms). This is equal to the hold up time (dt) from the above equation, and dv is the amount of voltage the circuit is allowed to droop. From the next section ("Determining Maximum Number of Series Connected LEDs Allowed") we know the minimum V_{BUCK} voltage will be about 45V for a $90V_{AC}$ to $135V_{AC}$ line. At $90V_{AC}$ low line operating condition input, ½ of the peak voltage is 64V. Therefore with some margin the voltage at V_{BUCK} can not droop more than about 15V (dv). (i) is equal to (P_{OUT}/V_{BUCK}), where P_{OUT} is equal to (V_{LED} x I_{LED}). Total capacitance (C7 in parallel with C9) can now be calculated. See " Design Example" section for further calculations of the valley-fill capacitors.

Determining Maximum Number of Series Connected LEDs Allowed:

The LM3444 is an off-line buck topology LED driver. A buck converter topology requires that the input voltage (V_{BUCK}) of the output circuit must be greater than the voltage of the LED stack (V_{LED}) for proper regulation. One must determine what the minimum voltage observed by the buck converter will be before the maximum number of LEDs allowed can be determined. Two variables will have to be determined in order to accomplish this.

1. AC line operating voltage. This is usually $90V_{AC}$ to $135V_{AC}$ for North America. Although the LM3444 can operate at much lower and higher input voltages a range is needed to illustrate the design process.
2. How many stages are implemented in the valley-fill circuit (1, 2 or 3).

In this example the most common valley-fill circuit will be used (two stages).

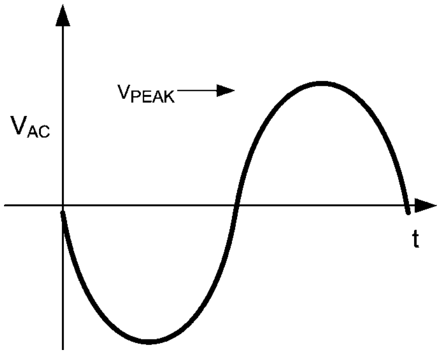


FIGURE 12. AC Line

Figure 12 shows the AC waveform. One can easily see that the peak voltage (V_{PEAK}) will always be:

$$V_{AC\text{-}RMS\text{-}PK}\sqrt{2}$$

The voltage at V_{BUCK} with a valley fill stage of two will look similar to the waveforms of *Figure 11*.

The purpose of the valley fill circuit is to allow the buck converter to pull power directly off of the AC line when the line voltage is greater than its peak voltage divided by two (two stage valley fill circuit). During this time, the capacitors within the valley fill circuit (C7 and C8) are charged up to the peak of the AC line voltage. Once the line drops below its peak divided by two, the two capacitors are placed in parallel and deliver power to the buck converter. One can now see that if the peak of the AC line voltage is lowered due to variations in the line voltage the DC offset (V_{DC}) will lower. V_{DC} is the lowest value that voltage V_{BUCK} will encounter.

$$V_{BUCK(MIN)} = \frac{V_{AC\text{-}RMS(MIN)}\sqrt{2} \times SIN(\theta)}{\#stages}$$

Example:

Line voltage = $90V_{AC}$ to $135V_{AC}$

Valley-Fill = two stage

$$V_{BUCK(MIN)} = \frac{90\sqrt{2} \times SIN(135^{o})}{2} = 45V$$

Depending on what type and value of capacitors are used, some derating should be used for voltage droop when the capacitors are delivering power to the buck converter. With this derating, the lowest voltage the buck converter will see is about 42.5V in this example.

To determine how many LEDs can be driven, take the minimum voltage the buck converter will see (42.5V) and divide it by the worst case forward voltage drop of a single LED.

Example: 42.5V/3.7V = 11.5 LEDs (11 LEDs with margin)

OUTPUT CAPACITOR

A capacitor placed in parallel with the LED or array of LEDs can be used to reduce the LED current ripple while keeping the same average current through both the inductor and the LED array. With a buck topology the output inductance (L2) can now be lowered, making the magnetics smaller and less expensive. With a well designed converter, you can assume that all of the ripple will be seen by the capacitor, and not the LEDs. One must ensure that the capacitor you choose can handle the RMS current of the inductor. Refer to manufacture's datasheets to ensure compliance. Usually an X5R or X7R capacitor between 1 µF and 10 µF of the proper voltage rating will be sufficient.

SWITCHING MOSFET

The main switching MOSFET should be chosen with efficiency and robustness in mind. The maximum voltage across the switching MOSFET will equal:

$$V_{DS(MAX)} = V_{AC\text{-}RMS(MAX)}\sqrt{2}$$

The average current rating should be greater than:

$$I_{DS\text{-}MAX} = I_{LED(\text{-}AVE)}(D_{MAX})$$

RE-CIRCULATING DIODE

The LM3444 Buck converter requires a re-circulating diode D10 (see the Typical Application circuit *Figure 2*) to carry the inductor current during the MOSFET Q2 off-time. The most efficient choice for D10 is a diode with a low forward drop and near-zero reverse recovery time that can withstand a reverse voltage of the maximum voltage seen at V_{BUCK}. For a common $110V_{AC}$ ± 20% line, the reverse voltage could be as high as 190V.

$$V_D \geq V_{AC\text{-}RMS(MAX)}\sqrt{2}$$

The current rating must be at least:

$$I_D = 1 - (D_{MIN}) \times I_{LED(AVE)}$$

Or:

$$I_D = \left(1 - \frac{V_{LED(MIN)}}{V_{BUCK(MAX)}}\right) \times I_{LED(AVE)}$$

Design Example

The following design example illustrates the process of calculating external component values.

Known:

1. Input voltage range ($90V_{AC}$ – $135V_{AC}$)
2. Number of LEDs in series = 7
3. Forward voltage drop of a single LED = 3.6V
4. LED stack voltage = (7 x 3.6V) = 25.2V

Choose:

1. Nominal switching frequency, $f_{SW\text{-}TARGET}$ = 250 kHz
2. $I_{LED(AVE)}$ = 400 mA
3. Δi (usually 15% - 30% of $_{ILED(AVE)}$) = (0.30 x 400 mA) = 120 mA
4. Valley fill stages (1,2, or 3) = 2
5. Assumed minimum efficiency = 80%

Calculate:

1. Calculate minimum voltage V_{BUCK} equals:

$$V_{BUCK(MIN)} = \frac{90\sqrt{2} \times SIN(135^{o})}{2} = 45V$$

2. Calculate maximum voltage V_{BUCK} equals:

$$V_{BUCK(MAX)} = 135\sqrt{2} = 190V$$

3. Calculate t_{OFF} at V_{BUCK} nominal line voltage:

$$t_{OFF} = \frac{\left(1 - \frac{1}{0.8} \times \frac{25.2V}{115\sqrt{2}}\right)}{(250\ kHz)} = 3.23\ \mu s$$

4. Calculate $t_{ON(MIN)}$ at high line to ensure that $t_{ON(MIN)}$ > 200 ns:

$$t_{ON\ (MIN)} = \frac{\left(\frac{1}{0.8} \times \frac{25.2V}{135\sqrt{2}}\right)}{\left(1 - \frac{1}{0.8} \times \frac{25.2V}{135\sqrt{2}}\right)} \times 3.23\ \mu s = 638\ ns$$

5. Calculate C11 and R4:
6. Choose current through R4: (between 50 µA and 100 µA) 70 µA

$$R4 = \frac{V_{LED}}{I_{COLL}} = 360\ k\Omega$$

7. Use a standard value of 365 kΩ
8. Calculate C11:
9.

$$C11 = \left(\frac{V_{LED}}{R4}\right)\left(\frac{t_{OFF}}{1.276}\right) = 175\ pF$$

10. Use standard value of 120 pF
11. Calculate ripple current: 400 mA X 0.30 = 120 mA
12. Calculate inductor value at t_{OFF} = 3 µs:

$$L2 = \frac{25.2V\left(1 - \frac{1}{0.8} \times \frac{25.2V}{115\sqrt{2}}\right)}{(350\ kHz\ x\ 0.1A)} = 580\ \mu H$$

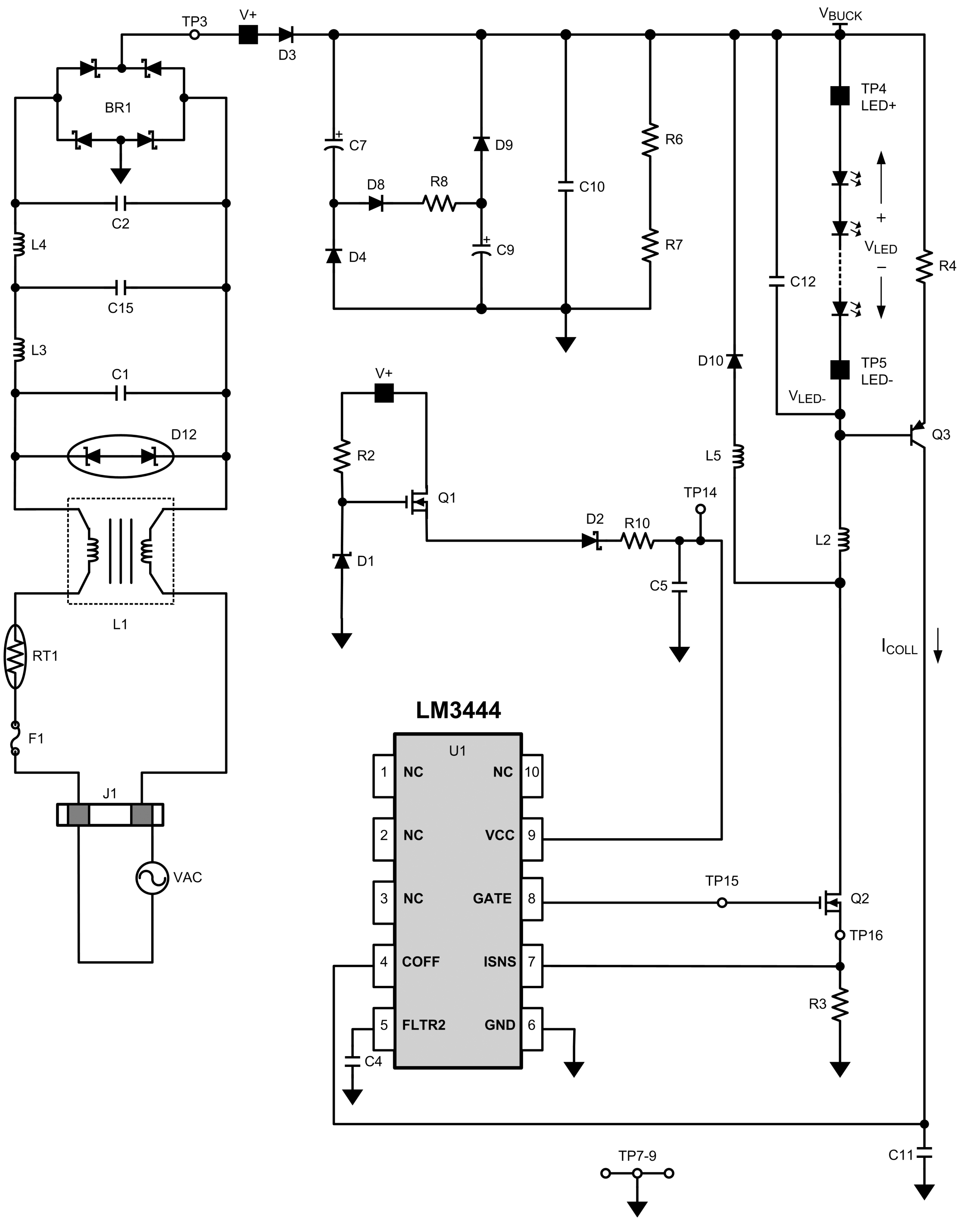
13. Choose C10: 1.0 µF 200V
14. Calculate valley-fill capacitor values: V_{AC} low line = $90V_{AC}$, V_{BUCK} minimum equals 60V. Set droop for 20V maximum at full load and low line.

$$i = C\frac{dv}{dt}$$

i) equals P_{OUT}/V_{BUCK} (270 mA), dV equals 20V, dt equals 2.77 ms, and then C_{TOTAL} equals 37 µF. Therefore C7 = C9 = 22 µF

LM3444 Design Example 1

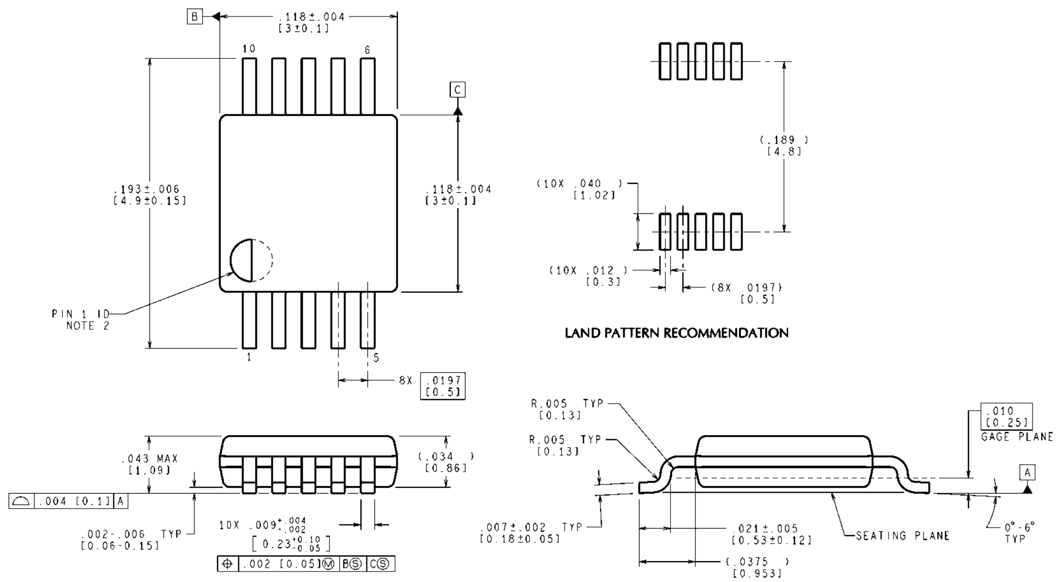
Input = 90V_{AC} to 135V_{AC}, V_{LED} = 7 x HB LED String Application @ 400 mA



Bill of Materials

Qty	Ref Des	Description	Mfr	Mfr PN
1	U1	IC, CTRLR, DRVR-LED, MSOP10	NSC	LM3444MM
1	BR1	Bridge Rectifiier, SMT, 400V, 800 mA	DiodesInc	HD04-T
1	L1	Common mode filter DIP4NS, 900 mA, 700 µH	Panasonic	ELF-11090E
1	L2	Inductor, SHLD, SMT, 1A, 470 µH	Coilcraft	MSS1260-474-KLB
2	L3, L4	Diff mode inductor, 500 mA 1 mH	Coilcraft	MSS1260-105KL-KLB
1	L5	Bead Inductor, 160Ω, 6A	Steward	HI1206T161R-10
3	C1, C2, C15	Cap, Film, X2Y2, 12.5MM, $250V_{AC}$, 20%, 10 nF	Panasonic	ECQ-U2A103ML
1	C4	Cap, X7R, 0603, 16V, 10%, 100 nF	MuRata	GRM188R71C104KA01D
2	C5, C6	Cap, X5R, 1210, 25V, 10%, 22 µF	MuRata	GRM32ER61E226KE15L
2	C7, C9	Cap, AL, 200V, 105C, 20%, 33 µF	UCC	EKXG201ELL330MK20S
1	C10	Cap, Film, 250V, 5%, 10 nF	Epcos	B32521C3103J
1	C12	Cap, X7R, 1206, 50V, 10%, 1.0 uF	Kemet	C1206F105K5RACTU
1	C11	Cap, C0G, 0603, 100V, 5%, 120 pF	MuRata	GRM1885C2A121JA01D
1	D1	Diode, ZNR, SOT23, 15V, 5%	OnSemi	BZX84C15LT1G
2	D2, D13	Diode, SCH, SOD123, 40V, 120 mA	NXP	BAS40H
4	D3, D4, D8, D9	Diode, FR, SOD123, 200V, 1A	Rohm	RF071M2S
1	D10	Diode, FR, SMB, 400V, 1A	OnSemi	MURS140T3G
1	D12	TVS, VBR = 144V	Fairchild	SMBJ130CA
1	R2	Resistor, 1206, 1%, 100 kΩ	Panasonic	ERJ-8ENF1003V
1	R3	Resistor, 1210, 5%, 1.8Ω	Panasonic	ERJ-14RQJ1R8U
1	R4	Resistor, 0603, 1%, 576 kΩ	Panasonic	ERJ-3EKF5763V
2	R6, R7	Resistor, 0805, 1%, 1.00 MΩ	Rohm	MCR10EZHF1004
2	R8, R10	Resistor, 1206, 0.0Ω	Yageo	RC1206JR-070RL
1	R9	Resistor, 1812, 0.0Ω		
1	RT1	Thermistor, 120V, 1.1A, 50Ω @ 25°C	Thermometrics	CL-140
2	Q1, Q2	XSTR, NFET, DPAK, 300V, 4A	Fairchild	FQD7N30TF
1	Q3	XSTR, PNP, SOT23, 300V, 500 mA	Fairchild	MMBTA92
1	J1	Terminal Block 2 pos	Phoenix Contact	1715721
1	F1	Fuse, 125V, 1,25A	bel	SSQ 1.25

Physical Dimensions inches (millimeters) unless otherwise noted



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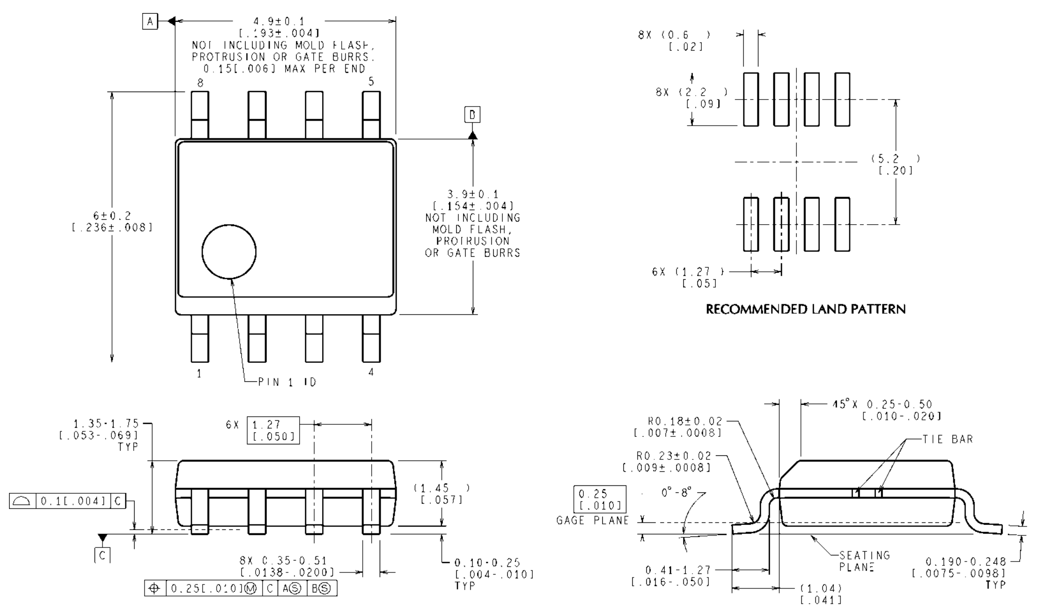
MUB10A (Rev B)

MSOP-10 Pin Package (MM)
For Ordering, Refer to Ordering Information Table
NS Package Number MUB10A



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M08A (Rev M)

SOIC-8 Pin Package (M)
For Ordering, Refer to Ordering Information Table
NS Package Number M08A

Notes